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THE PHENOMENA OF FLOCCULATION AND DEFLOCCULATION *

BY

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[The behavior of fine particles suspended in water is now attracting much attention from both theoretical and practical viewpoints. Especially important is the flocculation of these particles or their tendency to gather into aggregates. This paper outlines the present knowledge of these phenomena of flocculation as they affect suspension and as they are affected by various external conditions, mainly the presence or absence of soluble salts, acids, alkalies, and organic colloids. The appendix discusses the phenomena of flocculation in soils.]

THE NATURE AND OCCURRENCE OF FLOCCULATION.

IF to a suspension of, say, fine clay in water one adds a little sulphuric acid the clay particles are seen to gather slowly into aggregates and subside. This appearance and the similar phenomena extending through the whole range of suspensions, colloidal solutions, etc., and induced by many and varied agents and circumstances, have received the name of flocculation. Fundamentally this means nothing more than the gathering together

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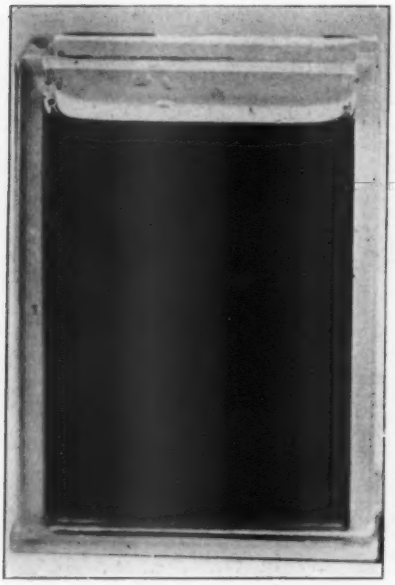
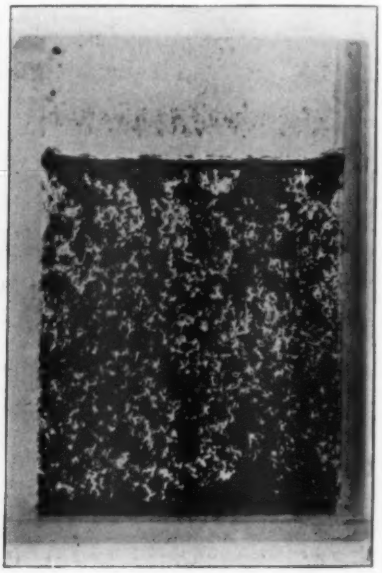
of the particles into aggregates, and all kinds of heterogeneous systems may therefore show similar or analogous phenomena. Some cases are shown in the following illustrations: Fig. 1 shows a suspension of very fine lampblack. Fig. 2 shows the same suspension after the addition of a flocculating agent. Fig. 3 shows five suspensions, originally similar, to four of which various flocculating agents have been added. The tube on the right is in the original condition. These matters have their

FIG. 1.



A non-flocculated suspension of lampback.

FIG. 2.



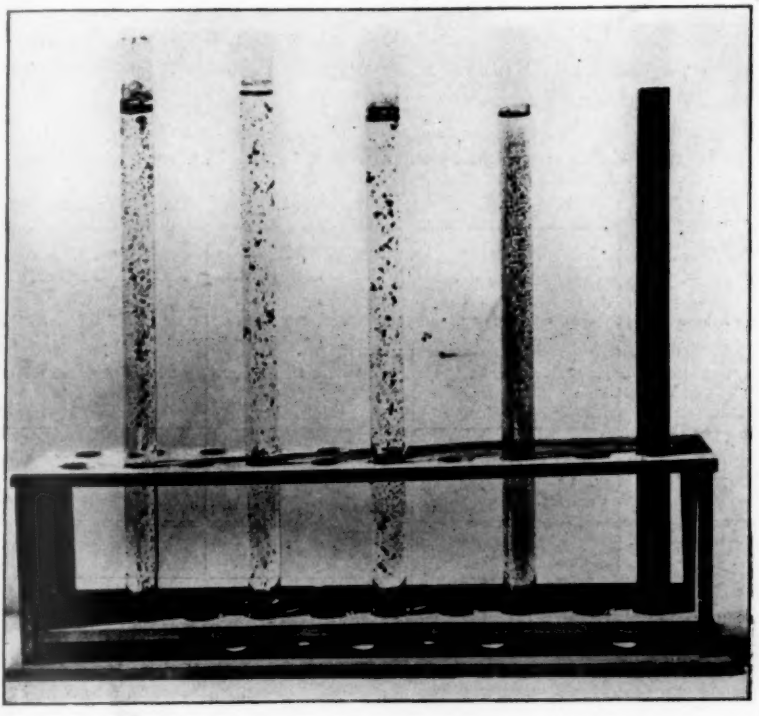
The same suspension as Fig. 1, but flocculated.

clearest and best illustration in the so-called "disperse" systems consisting of very fine particles distributed through a dissimilar medium, and typified by the well-known suspensions and emulsions.

With these systems we must include not only those suspensions and emulsions whose particles are individually or collectively visible to the eye or under the microscope, but also the great class of bodies known as colloids, which recent research has shown to be simply suspensions of particles which are extraordinarily small—

too small to be detected by ordinary optical methods. The most important result of the many investigations [1] made in this field in the last decade is the conclusion, now well established, that all of these apparently dissimilar bodies are fundamentally the same, and that no sharp separation can be made anywhere in the un-

FIG. 3.



Tubes containing flocculated and non-flocculated suspensions.

broken series from, say, a temporary suspension of quartz sand in water to a "solution" of colloidal silica. In fact if one accepts the molecular hypothesis and the ordinary forms of the

[1] Without unduly increasing the bulk of this paper it would be impossible to give citations to the original authorities for the various facts and theories mentioned. There is appended, however, a short bibliography of some of the more important works. The general works there cited under Freundlich, Ostwald and Zsigmondy respectively will furnish ample means toward further acquaintance with the literature.

solution theory, the "true" solutions themselves may be regarded as but disperse systems in which the particles are so small as to attain the dimensions of the molecule or the ion.[2]

The most important deduction from this generalization is that the colloidal state is possible for any substance which can be made to take and retain the requisite fineness of division. Colloids are not special bodies but bodies in a special condition; and the substances known to exist in this condition are simply those for which we know how to attain and preserve the required degree of division. With the advance of studies in this field the

TABLE I.

Classification of Disperse Systems According to the Nature of the Phases.

	Solid medium.	Liquid medium.	Gaseous medium.
	Class 1.	Class 4.	Class 7.
Solid particle....	Crystal inclusions and most colored crystals. Solid solutions.	Suspensions. Solid-particle colloids. Solutions (limiting case).	Smoke. "Dry fog." Dusty air.
	Class 2.	Class 5.	Class 8.
Liquid particle..	Liquid inclusions in crystals. Liquids absorbed by metals.	Emulsions. Liquid-particle colloids. Miscible liquids (limiting case).	Steam and cloud. Wet fog.
	Class 3.	Class 6.	
Gaseous particle	Gas inclusions. Gases absorbed by metals.	Foams. Gas suspensions.	No known examples.

number of known colloids is increasing daily, and there seems every reason to believe that any body whatever can be made to exist in the colloidal condition if a suitable medium and proper surrounding conditions be secured. Similarly the phenomena of flocculation are phenomena general to all bodies which can be kept in suspension, either temporary or permanent; and are apparently affected only in qualitative ways by the

[2] It is indeed an experimental fact that the continuity of the series above mentioned does extend into the realm of "solution," and that "colloids" shade gradually into "solutions," as do "suspensions" into colloids.

special properties of the suspended substance or the medium of suspension.

In addition to the rough classification of disperse systems according to size of particle[3] (into coarse or "true" suspensions, colloids, and "true" solutions), it is possible to classify them also according to the natures of the suspended particles and of the medium. One may have a suspension of solid particles in a liquid medium, of liquid particles in a gaseous medium, etc. With two-phase systems (which are the only ones here discussed) there are nine possible combinations as indicated in Table I. Of "suspensions" of gases in gases there are obviously no tangible examples, but the other eight classes are fully represented in reality, and illustrations are given in the table. Flocculation phenomena are known to occur in all of these classes of disperse systems, but for practical purposes two classes only are of importance, namely, the "suspensions" of solids in liquids, and the "emulsions" of liquids in liquids. In a limited paper it is impossible to discuss all of the cases even in these two classes, and I shall therefore limit myself to a consideration of suspensions of solid particles in water and to such of those suspensions as are composed of particles larger than the upper limit commonly assigned to the field of colloids,[4] —that is, to "true" or "coarse" suspensions of solids in water.

THE MECHANICS OF SUSPENSION.[5]

Having thus focussed our attention on a very small part of the whole field of flocculation phenomena, it remains only by way of introduction to speak briefly of the laws which control the suspension and subsidence of fine particles in water, and particularly of the effects of flocculation on the acting forces. The resistance to the passage of a body through a viscous medium increases with the velocity, and when a body moves through such a medium under the action of gravity its velocity is accelerated until it reaches a definite limiting value which is there-

[3] Or better, "degree of dispersion."

[4] Usually taken as a diameter of one-tenth of a micron or one ten-thousandth of a millimetre.

[5] At the request of some members of the Institute, there is given in the second part of the appended bibliography a list of some of the more important references on this subject. The subject is treated in most advanced text-books of mechanics and hydrodynamics.

after constant so long as the conditions remain unchanged. For the case of small spheres this constant final, or limiting velocity has been shown by Stokes and others to be equal to

$$v = \frac{2}{9k} r^2 (d - d^1) g;$$

where k is a constant expressing the viscosity of the fluid, r is the radius of the sphere, d and d^1 are the densities of the particle and the fluid respectively, and g is the acceleration of gravity. For fine particles in water the "v" of this formula is soon attained and represents sufficiently well the rate of sedimentation. It is apparent therefore that the variables which actually influence this rate are: (1) the difference of the densities, (2) the viscosity of the medium, and (3) the radius of the particle. The rate varies directly as the first, inversely as the second and directly as the square of the third. In actual experiment this formula holds sufficiently well for particles of appreciable size, but with very fine particles many irregularities appear and are probably to be ascribed to the action of surface forces, absorption effects, etc., which are still very imperfectly understood, and whose effects become perceptible only with the great relative increase of surface which accompanies fine division. Further, this formula is derived for particles of spherical form and can be applied to them only. For other and less regularly formed particles, not only does the surface increase in greater ratio to the radius (this increase occasioning a relatively greater importance of the viscosity factor), but there appears a new factor dependent on the shape and which we may conveniently designate the shape-factor. In the present state of knowledge this factor is not susceptible of precise analysis. One can but say that, other things equal, it causes the more irregular particles to fall more slowly.[6]

For present purposes the varied effects of density, viscosity, and shape of particle may be passed with a mere statement of their existence. The size of the particles is more important, and requires some discussion. It is evident, first, that for a finite size of particle the velocity of fall can never become zero, for viscosity, unlike the surface friction of solids, has no term for

[6] As an example of its action, the rate of fall of mica flakes is less than of the more regular grains of other minerals.

friction of rest. *Theoretically,* therefore, permanent suspension cannot occur with particles the density of which differs from that of the surrounding medium. Practically, however, since the velocity of fall varies with the *square* of the radius, it is easily possible to find particles so small that their fall is almost infinitely slow, so slow in fact as to be entirely counteracted by convectional and other circulations which it is impossible entirely to eliminate from the medium itself. Practically permanent suspension is therefore possible by the action of well-known physical factors, even without the necessity of invoking those chemical combinations, and electrical and molecular-kinetic actions which seem to come into play in the finer-grained of the disperse systems.

Applying this now to flocculation, it is apparent that if the radius of the particle exerts such a controlling influence on the rate of settling, and if (as is obvious) the flocculation of the particles increases the effective radius, flocculation must have the effect of greatly increasing the ratio of sedimentation and therefore of hastening the clearing of suspensions. This is in fact the chief way in which flocculation is made manifest and from this fact comes the common use of the word flocculation as signifying an increase in the rate of clearing of a suspension. Especially "deflocculation" has come to mean a decrease in the rate of clearing, and suspensions are said to be "deflocculated" when they settle very slowly or not at all. Of course these uses of the words are perfectly legitimate, for, if the ultimate particles be sufficiently fine, their state of aggregation (or flocculation) is really the controlling factor in the rate of clearing, and those factors which affect this rate do so usually by affecting the degree of flocculation.

THE DEGREE OF FLOCCULATION.

It is obvious that the terms flocculation and deflocculation (like "high" and "low," "soluble" and "insoluble," etc.) are relative only. The suspension in which the particles are gathered into the larger aggregates, or in which sedimentation goes on more rapidly is the more flocculated regardless of the absolute size or census of the aggregates or the absolute value of the rate of settling. The minimum of flocculation (or the maximum of deflocculation) is reached when all particles exist individually

and there are *no* aggregates. Any system in which the particles are gathered even very slightly into aggregates is "flocculated" in comparison, though it may itself be "deflocculated" in comparison with a system exhibiting still more complete aggregation. Neither does it follow that a system which is called deflocculated possesses the maximum of deflocculation defined as the existence of every particle in separate condition. For instance, an alkaline clay suspension or Mr. Acheson's deflocculated graphite—both rightly classed as deflocculated—can each be shown to contain many aggregates. It is very probable indeed that the ideal maximum deflocculation does not exist in nature in the class of suspensions under discussion.

Strictly then we should speak of the *degree of flocculation* of a system rather than of its existence in a "flocculated" or "deflocculated" condition, and the thing which mainly concerns us is the effect of various agents and surroundings upon this degree of flocculation. For this degree of flocculation, like most other properties of heterogeneous systems, depends not so much upon the components of the system as upon the energy potentials at which it is placed. For a particular combination, as, *e.g.*, kaolin in water, there is no definite and fixed state of flocculation. The degree of flocculation is widely variable and depends upon the general surroundings of the system: the temperature, the electric changes, the presence of other bodies, and many other factors still but dimly sensed. It is not only possible but easy to change the degree of flocculation of any suspension (excluding the extreme cases of solutions, etc.), and these dynamic relations are really the "phenomena of flocculation and deflocculation" in the active sense of this expression.

Of energy changes affecting the degree of flocculation we know very little and that little almost entirely from studies on the colloids. Whether the results here obtained are applicable to the larger-particle systems to which we wish to devote attention is at least an open question. We do know, however, that the effect of rise of temperature is practically always to increase the degree of flocculation, and hence the rate of settling. Radiant energy both in the form of light and of the rays from radium and from electrical excitations, seems also to have important influences, but the data here are still contradictory and uncertain. Electrical charges and their changes are known to

be of great importance, but as we are still unable to control the electrical energy of systems of this kind, the data on these points are mainly indirect and can be better discussed after some mention has been made of the effects of added substances.

The addition of many material agents, sometimes in very small amount, has a great influence. Indeed this is the main way in which changes in flocculation are brought about in practice, and here lie the main technical applications of the phenomena. Of the bodies which have large influences the main are the stronger alkalies and the organic colloids which decrease the degree of flocculation, and neutral salts and acids which increase it. The former are the "deflocculators," the latter the "flocculators."

These statements are subject to many exceptions and qualifications, and will require closer examination, but as a preliminary thereto it may be well to say a word as to the "normal" degree of flocculation of a system, or that which would exist in the absence of any bodies other than the suspended particles and the medium. There is a general impression that this "normal" degree of flocculation would be the absence of any flocculation at all—that a suspension of, say, fine quartz in pure water would be entirely deflocculated and would remain in nearly permanent suspension. Recent work in our own laboratory has cast much doubt upon the correctness of this impression. The investigation is one of great difficulty because of trouble in obtaining pure materials, and our results are not as yet final; but it seems that the more we purify water the less readily will kaolin remain suspended in it, and it is probable that with absolutely pure water we would obtain a certain medium degree of flocculation intermediate between those obtainable when other substances are present. The exact position of this intermediate, normal degree of flocculation remains unknown and would probably vary with the substances employed and with the energy potentials. The important point, as before, is the possibility of modifying in various ways this normal degree of flocculation, and especially by action of added materials.

There is, however, the interesting conclusion that the so-called "permanent" suspensions of clay, kaolin, etc., of which much has been made in the literature are really permanent, or

nearly so, because of impurities [7] in the water, which impurities prevent the flocculation and subsidence which would normally take place.

THE EFFECTS OF DISSOLVED SALTS ON SUSPENSIONS.

If to one of two jars containing kaolin suspended in ordinary water one adds a little common salt or a little sulphuric acid, the kaolin immediately begins to flocculate and settles out much more rapidly than in the companion jar to which nothing was added. On the other hand if instead of sulphuric acid or common salt one adds ammonia or caustic potash, the degree of flocculation is decreased and the kaolin remains suspended much longer than in pure water. If the ultimate particles are fine enough they will not subside at all. These are simple and well-known examples of the action of salts, acids and alkalies on suspensions.

As already mentioned, the stronger alkalies are, in general, deflocculators; all salts and acids are flocculators (though with great differences of intensity). These actions are, however, not so simple as this statement. The effects vary in different concentrations and there are many complexities and anomalies which still require elucidation. Such cases must be left unnoticed. In this paper it is possible only to touch on certain of the more general principles, making full acknowledgment that their generality is yet to be established, and that they will doubtless require and receive severe modification as knowledge advances in this field.

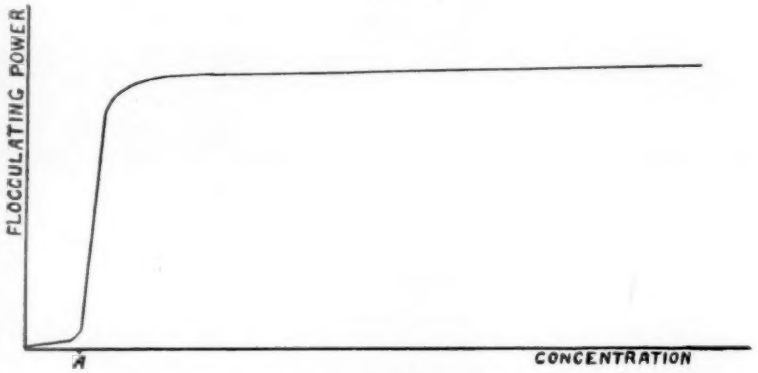
Turning first to the actions of the flocculating agents—the acids and the neutral salts—and considering the effects of varying concentrations of these bodies, the most noticeable fact is that a certain minimum concentration of the salt in the solution is necessary before there is any apparent action on the suspension. The absolute value of this initial active concentration varies with the different salts, but once attained, the flocculating action on the suspension begins suddenly and continues rapidly. Further increases in concentration produce comparatively little effect. The matter is illustrated by the ideal curve of Fig. 4, in which the concentration is represented on the horizontal axis and the

[7] Mainly organic colloids.

intensity of the flocculating action on the vertical. The initial or "threshold" concentration at which action first becomes apparent is represented by the point *A*. For the ordinary salts and acids this initial concentration is very low. In many cases mere traces are sufficient.

Next in importance to the effect of concentration is the effect of the chemical nature of the flocculating salt, and here we have two general rules, both of which have been developed mainly for colloids. The first is due to Hardy[8] and states that a suspension (or colloid) will be flocculated only by a solution or another suspension whose ions or particles are of opposing

FIG. 4.



Ideal curve showing the relation of the flocculating power to the concentration in solutions of most acids and neutral salts.

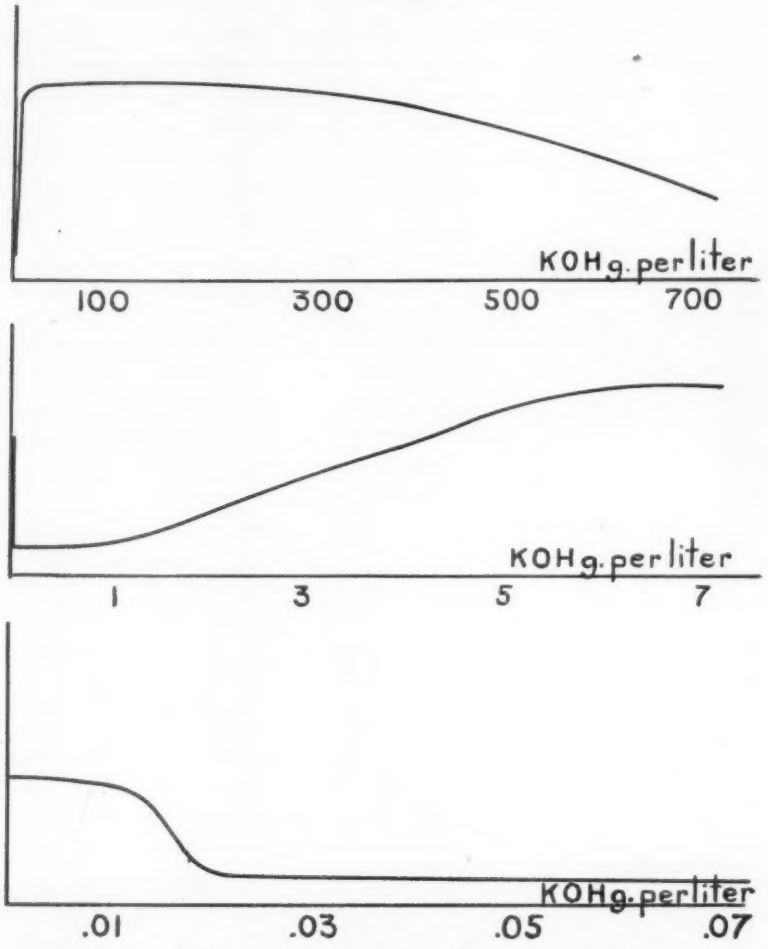
electrical sign. That is, a suspension the particles of which carry negative charges will be flocculated only by a solution containing positive ions and *vice versa*. This holds fairly well for colloids and the exceptions which do exist can probably be explained. In coarser suspensions the rule is of less utility. It seems probable that it is still applicable but that its operation is more often obscured by other factors which are there more powerful.

The second rule is that of Schulze,[9] and says that the flocculating power of an ion increases very rapidly with its valence. The flocculating power of the bivalent elements is greater than that of the monovalent, that of the trivalent is still greater,

[8] Proc. Roy. Soc., London, **66**, 115 (1899).
[9] Jour. prakt. Chem. (2) **25**, 445–446 (1882).

etc. This rule has also been derived for colloids, holds fairly well there and less well for coarser suspensions, and, like the other, probably fails of complete correspondence with observa-

FIG. 5.



Relation of flocculating power to concentration in solutions of potassium hydroxide.

tion, not because it lacks validity, but because its effects are so often obscured by other actions still not understood. These matters will be clearer after the theory of the phenomena has been outlined.

Turning now to the bodies of opposite tendency, the deflocculators, we find that the class includes only the stronger alkalies,—the hydrates and carbonates of potassium, sodium, lithium and ammonium, and of the rare metals cæsium and rubidium.[10] The effects of different concentrations of these bodies have recently received some light from investigations (not yet published in detail) which have been carried on by Dr. F. K. Cameron and myself. Working with purified kaolin in water we have studied the effects of solutions of potassium hydroxide over the whole range of concentrations from zero to the point of saturation for ordinary temperatures. The results are given in the three ideal[11] curves of Fig. 5. The first curve shows the relations over the whole range of concentrations. The very dilute solutions show what appears to be a sudden drop corresponding to a strong deflocculating effect (the characteristic effect of dilute alkali on suspensions), followed, surprisingly, by an apparently sudden rise to a fairly strong *flocculating* power, thus reversing the effect of the dilute solutions. This flocculating power gradually decreases with increase of concentration, but this decrease is probably more apparent than real and seems to be due to the increasing viscosity and density of the solution which decreases the rate of fall of the aggregates and simulates a lower degree of flocculation. The conditions in the dilute solutions are shown better in the two following curves which show respectively 1/100 and 1/10,000 of the top curve. From the middle curve it is apparent that after the first drop there is a *range* of concentrations over which the action is a strong deflocculation. There is then a somewhat gradual increase up to the maximum of flocculating power. The lowest curve shows the behavior of very dilute solutions and furnishes a good illustration of the initial or "threshold" concentration which is necessary before action begins, and is analogous to that already described for the flocculating salts.

The other fixed alkalies show curves of the same general character, and, with slight modifications, the same is true of the carbonates of potassium and sodium. Ammonia, however, gives only the deflocculating effect, the curve shows the first

[10] The hydroxides of calcium, barium and strontium are uncertain in their action and require further study.

[11] Ideal only because of the lack of a direct measure of flocculation.

drop substantially as in the lowest curve of Fig. 5, but the following rise to a flocculating effect does not occur. The region of deflocculation extends throughout the concentrations obtainable at ordinary pressures.

THEORY OF THE ACTIONS OF DISSOLVED SALTS.

At present no complete or perfect theory of these actions can be formulated, nor would it be a proper part of a paper on the *phenomena* of flocculation. There are, however, a few general lines of suggestion to which it may be well to give brief attention; for, purely conjectural as these statements may be, they nevertheless form useful racks on which to hang separate bits of information and through which we may be able better to co-ordinate and make use of what we think we know.

Probably the best way to approach this field of theory is to inquire along what lines we might expect, *a priori*, the suspension systems to be influenced by added bodies. Two of these at once suggest themselves and the complete theory will probably include them at least, whatever others it may prove necessary to add. These two are the effects on solubility relations and on electric charges.

For an understanding of the first of these it is necessary first to recognize that the separation between each suspended particle and the medium surrounding it is seldom a sharp one. The best instances are the emulsions. An emulsion of, say chloroform and water really consists of a solution of chloroform in water in which are suspended droplets of a solution of water in chloroform. The droplets of chloroform dissolve to some extent in the water and the water dissolves in the chloroform. This mutual solubility of the two bodies probably has a great effect on the character of the surface of the particles, and since the nature of this surface is known to be active in controlling sedimentation and flocculation, it is to be expected that the amount of the mutual solubility will importantly influence the latter phenomena. But soluble bodies are likely to influence the solution equilibria of systems to which they are added, and it is therefore probable that their addition to emulsions will have noticeable effects on the mutual solubility of the particle and the medium, hence on the surface of the particle, and finally on the degree of flocculation. In the chloroform-water emulsion

above mentioned the addition of a salt to the chloroform-in-water solution (the medium) will usually influence the solubility equilibrium between this and the water-in-chloroform solution (the particle); the quantities of water dissolved in the particles and of chloroform dissolved in the medium will change; and the surfaces of the particles, the degree of flocculation, and the other properties may change in turn.

These relations are most obvious in the case of emulsions, but they apply, changed only in degree, to the solid-particle suspensions. It is known that the separation between a particle and a liquid medium is not sharply at a surface, even if the particle be solid. There is a certain amount of penetration of the liquid into the solid, or more exactly, of interpenetration of solid and liquid. It is obvious that added substances may have on this interpenetration the same sort of action as just described for the emulsions, and it is probable that the flocculation phenomena of solid-particle suspensions are really influenced in this way, though the effects are not likely to be so distinct or so great as in the emulsions. The mutual solubilities in the latter case are larger and changes in them probably play a greater rôle.

Here belong also the various phenomena of adsorption which seem to be essentially modifications of the concentrations and solubility relations in the zones very close to surfaces of separation. These phenomena have certainly much to do with surface conditions and many parallelisms between them and flocculation have been discovered.

The second way in which dissolved salts may act on suspension is by changing the charges of electricity which are known to be resident on the surfaces of the particles. The action of these charges on flocculation might be either direct or indirect. In the first case the mechanism would be ordinary electro-static repulsion. When the particles were all charged and of the same sign, there would be a repulsive force tending to prevent flocculation. The addition of salt solutions furnishes a means of changing the charges [12] on the particles and hence of modifying this electro-static resistance to flocculation. If the

[12] Probably because of charges resident on the ions in the solution. For details on these points reference must be made to text-books of electro-chemistry.

charges on the particles be reduced to zero, this resistance to flocculation will disappear and flocculation may take place. There are in fact certain colloids and suspensions for which the point of zero electric charge (the "iso-electric point") corresponds to the greatest degree of flocculation (or the maximum instability), and in these cases the direct electro-static action is probably the main controlling factor. In other cases the correspondence is not so good, and for them other factors are probably predominant or important.

The indirect electric actions are due to the effects of electric charge in opposing or assisting the various surface tensions and other forms of energy resident on the surfaces of suspended particles. The nature and action of these forms of energy is as yet very little understood and the effects of electric charge on them must be passed with a mere statement of their existence. It is probable, however, that these indirect effects far surpass the direct ones in magnitude and in frequency of occurrence.

It may be pointed out in passing that the actions of electrical charges on suspensions may be used to explain the rules of Hardy and Schulze above mentioned. The action of suspensions of opposing charge in precipitating each other may obviously be ascribed to neutralization and the destruction of the electro-static resistance to flocculation. The increase in the flocculating activity with increase in valence of the active ion is explainable on the supposition (already reached on electro-chemical grounds) that the charge carried by an ion increases with its valence.

It seems probable, therefore, that two of the ways in which dissolved bodies influence the phenomena of flocculation are by acting on the mutual solubility of the particle and the medium, and by changing the electric potential at the surface of the two. Assuming that these actions can go on side by side and in varying degree, with the predominance now of one and now of the other, we have a reasonable explanation of the almost infinite complexity of the *resultant* actions which we actually observe. Add to this the known existence of still other factors of which we have as yet no understanding, and the existing confusion of knowledge does not seem surprising.

No claim is made that these two actions are the only ones which such substances have on suspensions, but they seem at the present time to be the most generally important, though

even this guarded statement may have to be modified as understanding of the phenomena becomes more clear. However, the assumption of simultaneous action in these two ways but in different degree in each case, fits quite well with certain known facts not easily explainable otherwise. For instance: if both of these actions are possible, the first (that of mutual solubility) will probably be most important in emulsions, and the second (that of electric charge) in the solid-particle suspensions. In emulsions the mutual solubilities are absolutely larger and their changes probably more important. In solid-particle suspensions, on the other hand the electric charges are usually much greater, while the mutual solubility (interpenetration) is usually not great. Now the action of additional dissolved substances on solubility relations is ordinarily a mass action and proportional to the amount of added substance, and it is at least a curious coincidence that in emulsions, where we would expect action on solubilities to predominate, this same mass action is found, and the flocculating effect is roughly proportional to the amount of flocculating salt which is present. With solid-particle suspensions no mass action is apparent. The action begins suddenly (at the "threshold" concentration) and shows practically no variation with increase in concentration. This is exactly the course of events to be expected if the action is due mainly to the neutralization of electric charge, for this would be completed by the addition of a definite amount of the neutralizing material.

Further, the action of soluble non-electrolytes, which may be expected to affect solubility relations but not electric charges, is generally much greater on emulsions than on solid-particle suspensions. The wide deviations from the electrical rules (those of Hardy and Schulze) for the action of flocculating salts are mainly in emulsions and liquid-particle colloids, where the mutual-solubility relations and not the electric charges are supposed to be in control. Finally, the hypothesis of the simultaneous occurrence of these two actions is in good accord with the observation of maxima and minima in the concentration-flocculation curves, as described for potassium hydroxide. There are indications of similar inversions in the curves for other bodies, and if these inversions be real, at least two factors of the same order must be in control of the phenomena. Change

of mutual-solubility, and of electric charge are two which are possible.

In spite of these agreements, it is however unsafe to claim for this theory any completeness or certain validity. There are many known facts for which it *fails* to account, and to explain which we must fall back on the convenient "unknown factors" —an evasive procedure at the best. The final theory of flocculation by dissolved salts is still to be reached, and the present pages are intended as suggestions and not solution.

(To be continued.)

FUTURE PENCIL WOODS.

Recent conferences of representatives of the Department of Agriculture with several lead-pencil manufacturers have resulted in plans for testing new woods to find out whether they can be used in the pencil industry. According to some of the manufacturers, the supply of red cedar, which furnishes practically all the wood for the annual output of some 325,000,000 pencils, will be exhausted within five years. A substitute must be found which will whittle easily, which shall contain a large amount of material free from knots, which shall not be porous, nor spongy, nor unduly hard, and which shall occur in sufficient quantities to meet the manufacturers' demand.

In view of this and at the suggestion of the pencil makers, the Forest Service is to coöperate in a test of a number of National Forest woods. Among those to be tried are Rocky Mountain red cedar, Alligator juniper, western juniper, redwood, incense cedar, western cedar, Port Orford cedar, and Alaska cypress. Wood specimens collected from the National Forests will be sent to four leading manufacturers, who have agreed to make pencils of them. The manufacturers will keep a record of the tests and report to the Forest Service the results, as well as their judgment as to the fitness of the individual woods.

The Forest Service is assisting in this experiment because there are on the National Forests large quantities of junipers and cedars which may be suitable for pencil manufacture. For several of these woods no very valuable use has yet been discovered. Foresters believe that in the future the woods from the National Forests may, to a considerable extent, come into use to supplement the diminishing stock of eastern woods, the supply of which has received no protection.

THE PHYSICAL PRODUCTION OF LIGHT.

BY

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(*Presented at a Stated Meeting of the Section of Physics and Chemistry, held Wednesday, March 16, 1910.*)

[The author considers briefly certain questions in physiological optics which determine the light giving properties of radiant energy and then discusses the laws of radiation and the radiating properties of metals. Particular attention is given to various new methods for determining selective radiation, and data obtained by these new methods is presented.]

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I. PHYSIOLOGICAL OPTICS.

LIGHT is a sensation. If there was no eye to see there would be no light, however many sources of radiant energy might be present. Conversely, if the eye were entirely shielded from the action of radiant energy, the sensation of light might still under certain conditions be experienced. The sensation, light, can be produced in two ways, which may be denominated as artificial and natural. Thus, if the eye is subjected to a shock, such as that occasioned by a violent blow upon the back of the head, the whole field of vision may be filled with an intense light. We familiarly say that we "see stars." Moreover, the action of mechanical pressure of moderate intensity upon a limited portion of the retinal elements may produce disks of light (called phosphenes) with darkly colored edges. Some observers have claimed that very strenuous excitation of the apparatus for accommodation occasioned in their eyes similar phenomena ("phosphenes of accommodation"). On making or breaking a weak electrical current sent along the optic nerve the entire field of vision is lighted up. And finally, the retina has a light of its own (Eigenlicht), for its nervous elements are rarely, if ever, inactive.

In contrast to this sensation of light produced artificially is the natural production of the sensation of light when radiant energy within the proper limits of wave-length, of sufficient intensity and of sufficient duration, falls upon the retina.

The present paper will be confined to a consideration of the production of the sensation of light by natural means, and moreover, will have to do rather with the physical properties of radiating bodies than with the physiology and psychology of the sensation proper.

It may be well, however, before proceeding to a discussion of the physical production of radiant energy, to outline very briefly

the qualitative and quantitative effects produced when the retina is subjected to energy of various wave-lengths and intensities.

The spectrum of an ordinary solid body, heated to incandescence, is usually divided roughly into three parts,—the infra-red or heat rays, the visible rays, and the ultra-violet or chemical rays. Of the first, or infra-red rays, radiations of wave-length extending down to 60 or 70μ ($\mu = 0.001$ mm.) have been studied, whereas the longest waves capable of producing the sensation of light in the human eye are in the neighborhood of 0.8μ. Between these two limits the heat rays are absorbed to a great extent by the media of the eye.[1] But there is still transmitted to the retina nine or ten per cent. of that incident on the outer surface of the eye. The eye, therefore, is not sensitive to these rays.

Radiant energy between the limits of 0.8μ on the red side to a little less than 0.4μ on the violet side produces the sensation of light. With moderately intense sources the eye can perceive rays of wave-length down to 0.38μ, but there is no sense of color beyond 0.4μ. If the eye were deprived of the crystalline lens, vision would be extended a little further to about 0.34μ. Beyond 0.38 or 0.4μ lies the ultra-violet spectrum, which has been studied down to a lower limit of approximately 0.1μ.

The proper admixture of all wave-lengths in the visible spectrum as also the proper admixture of three primary colors in the visible spectrum will produce the integral effect of white light. The question naturally arises "What are the relative intensities of sensation produced by equal quantities of energy per second in different parts of the visible spectrum?". Thus, will so many watts of power in the violet end of the spectrum produce the same intensity of sensation as the same number of watts in the green?

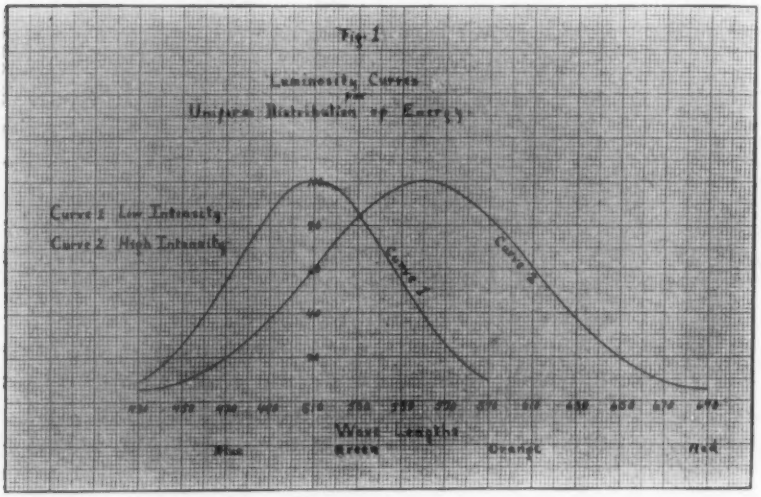
The answer to this question is given in the sensibility curves of the eye. Curve 1, Fig. 1, plotted from Koenig's data,[2] shows the relative intensity of sensation in different parts of the visible spectrum corresponding to a uniform distribution of energy through the spectrum and when the absolute value of the effective illumination is quite low. It will be noticed that the eye is most sensitive to light of wave-lengths in the vicinity of $\lambda = 0.51\mu$, and least sensitive to energy lying near the limits of the visible spectrum. If, therefore, we had at our disposal a given small quantity of luminous energy that could be radiated in waves of

any length we should choose, we would obtain the greatest illumination if the energy were radiated in rays of wave-length of approximately 0.51μ. The color of the light would be green.

Now as the absolute intensity of the radiation increases, the shape of the sensibility curve is changed, the wave-length of maximum sensibility shifting toward the red end of the spectrum. This phenomenon was first discovered by Purkinje from whom it has received its name.

In curve 2 is given the sensibility curve corresponding to

FIG. 1.



equal energy in different parts of the spectrum, but when the absolute intensity is relatively high. It is seen that the maximum sensibility is no longer in the green at 0.51μ but has shifted to about 0.56μ in the yellow green.

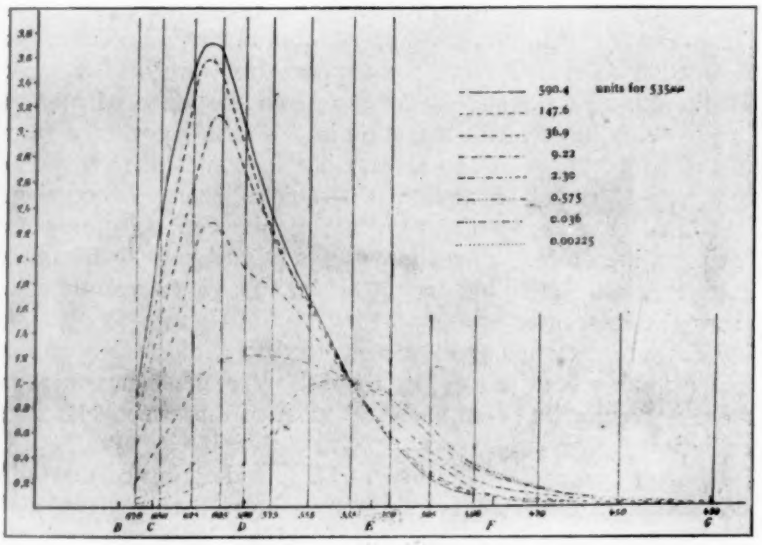
Curves 1 and 2, as stated above, are luminosity curves for equal distribution of energy throughout the visible spectrum. No source that we know of has such a uniform distribution, so that the wave-length of the energy producing the maximum sensation is usually shifted toward the red end of the spectrum, since in most luminous sources there is a preponderance of energy in the longer wave-lengths.

In Fig. 2 are shown the luminosity curves at different abso-

lute intensities of illumination for light from a triple gas burner.[3] These curves are plotted so that the ordinates are in every case equal to unity at wave-length $\lambda = 0.535\mu$. In the upper right-hand corner are given the absolute intensities of illumination corresponding to $\lambda = 0.535\mu$. The unit in terms of which the values are expressed, is about 0.1 of a foot-candle. These curves show very strikingly the Purkinje phenomenon.

It is evident from the above considerations that if a luminous source is to have the highest efficiency not only should all of the

FIG. 2.



energy delivered to the source be emitted in the form of radiant energy of wave-lengths lying within the range of the visible spectrum, but it should be emitted in radiation of the wave-length corresponding to the position of maximum luminosity in the visible spectrum, which for high intensity would lie in the neighborhood of $\lambda = 0.56\mu$. The color of such a source would be yellowish-green. No white light source could be quite as efficient, since in order to produce the white color some of the energy would have to be radiated in wave-lengths of lower luminosity. The most efficient white light would only have an efficiency of

approximately 40 per cent. of the efficiency of monochromatic light of wave-length $\lambda = 0.56\mu$.

II. THE LAWS OF RADIATION.

Every body in nature radiates energy in one form or another. There are, however, two kinds of radiation to be distinguished.

1. If a body does not undergo any change in its nature during the process of radiation, it would continue to radiate in the same way if, through the constant addition of heat, its temperature were held constant. This kind of radiation is commonly known as pure temperature radiation.

2. If, on the other hand, the body undergoes change during the process of radiation, it would not continue indefinitely to emit this radiation even though the temperature were held constant. To this kind of radiation has been given the name of *luminescence*. The cause of the radiation in this case is not to be found in the temperature of the system but in some other source of energy. Thus, for example, if the radiated energy is occasioned by chemical changes, the resultant luminescence is known as chemiluminescence. Phosphorescence is an example of photoluminescence. The light from Geissler tubes is frequently called electroluminescence.

The present paper will be restricted to a discussion of pure temperature radiation, since this is by far the commoner and more important form met with in most of our practical sources of light.

Before proceeding, however, to a consideration of the radiation from material substances, it may be well to review briefly the various properties of the theoretical black body. Even though the radiation may be due entirely to the temperature of the body, the quantity and quality of the energy radiated by material bodies at the same temperature, depend on the nature of the bodies themselves. Only in the case of an absolutely black body is the radiation simply a function of the temperature.

By a black body is meant a body that will neither reflect nor transmit any of the energy incident on it. We say charcoal and platinum oxide are black because they absorb most of the energy of all wave-lengths in the visible spectrum. They are not entirely black, however, because they reflect some energy in the visible spectrum, and even more in the infra-red spectrum. In

order to be perfectly black they should absorb all the energy incident upon them—not only in the ultra-violet and visible regions of the spectrum, but also all of the energy of the infra-red or heat spectrum.

As stated in Kirchhoff's law: A body which at a given temperature absorbs energy of a given wave-length will at the same temperature emit energy of that wave-length, and the ratio of the absorption to the emission is a constant. Thus, if one of two bodies absorbs twice as much red light as the other body, it will, at the same temperature, emit twice as much. It is readily seen from this that a theoretical black body which absorbs all of the energy of all wave-lengths incident on it, must emit more energy of every wave-length than any other body at the same temperature.

As stated above, no body in nature is black or even approaches very closely to blackness, but carrying out a suggestion of Kirchhoff, Lummer and Kurlbaum [4] were able experimentally to realize very closely the theoretical black body by the use of a uniformly heated hollow enclosure with a small opening through which the radiation passes. This form of black body has been employed in the various experimental investigations of the laws of black-body radiation.

The principal laws which have been derived from both theory and experiment for the radiation from a black body are as follows:

STEFAN–BOLTZMANN LAW:

$$E = K(T^4 - T_0^4)$$

WIEN'S LAWS:

$$\lambda_m T = \text{constant} \quad A \qquad J_{max} T^{-5} = \text{constant} \quad B$$

$$J = C_1 \lambda^{-5} E^{-\frac{C_2}{\lambda T}}$$

PLANCK'S LAW:

$$J = C_1 \lambda^{-5} \frac{1}{E^{\frac{C_2}{\lambda T}} - 1}$$

The first is what is known as the Stefan–Boltzmann law which states that the total energy radiated is proportional to the fourth power of the absolute temperature.

Of Wien's three laws, the first one, known as the "Displacement Law," states that the product of the wave-length of maximum energy times the absolute temperature is equal to a constant. This constant for a black body is in the neighborhood of 2940°, so that for an absolute temperature of 2940°, the wave-length of maximum energy would be 1.0μ, or well beyond the red end of the visible spectrum.

The second law, which is deduced from a combination of the Stefan–Boltzmann and the Displacement Laws, gives the relation between the temperature and the maximum emission in the spectrum.

Thus, these two laws of Wien, taken together, give for a definite temperature T the wave-length at which the maximum energy is radiated and the intensity of radiation of that wave-length.

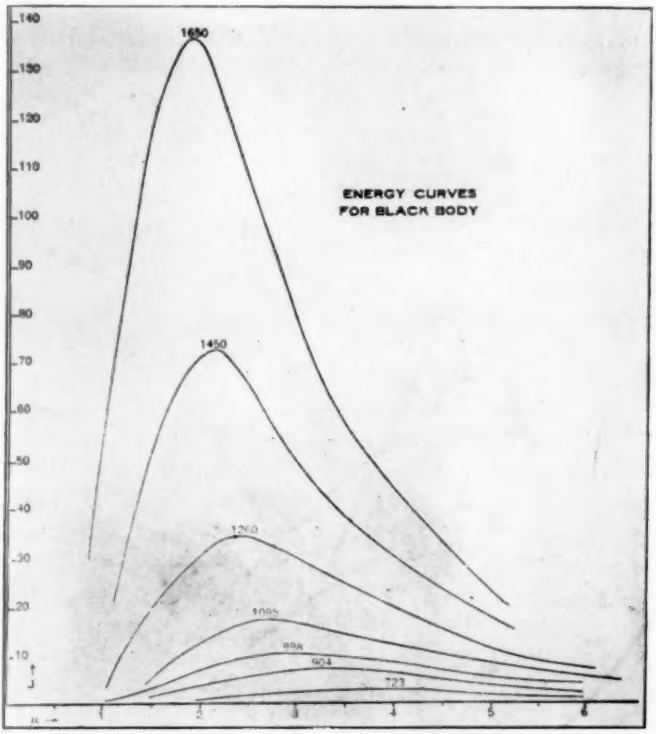
Wien's third law undertakes to give the energy radiated in any wave-length and at any temperature of a black body.

Planck's law is another statement of this relation between energy, wave-length and temperature, which perhaps has a better theoretical foundation and which agrees better with observed facts—particularly in the region of longer wave-lengths. From Planck's equation, knowing the constants C_1 and C_2 which have been determined experimentally, it is possible to plot the energy curve for any absolute temperature T. In Fig. 3 are given a number of such curves corresponding to different temperatures. It is immediately evident that as the temperature is raised, not only is the energy of every wave-length increased, but also that the increase is greatest for the shorter wave-lengths and relatively less for the longer wave-lengths, so that the position of maximum energy is shifted toward the shorter wave-lengths.

With this very brief summary of the properties and laws of the theoretical black body, let us consider for a moment in what ways the pure temperature radiation from a material substance may differ from the radiation from a black body. As stated above, the black body from its very definition, must at a given temperature emit more energy of every wave-length than any other body at the same temperature. Consequently, a material body may differ from a black body in that it emits at a given temperature one-half or one-third or one-fourth of the energy of every wave-length of that emitted by the black body at the same

temperature. The energy curve of such a body would be identical with that of a black body with the exception that its ordinates would be reduced proportionally throughout the entire spectrum. Such a body is sometimes known as a *gray* body. It can be realized experimentally by interposing between the

FIG. 3.



Energy distribution in black-body radiation.

above described experimental black body and the screen on which the radiation falls a rotating sectored disk of various apertures. Thus, if the total aperture of the disk were 180°, it would reduce by one-half the energy of every wave-length emitted by the black body. If the aperture were 90°, it would transmit one-fourth the energy of the black body. In both cases, the radiation would be that of a gray body, that is, the same in quality but

less in quantity than that of a black body at the same temperature. It is evident that there can be an infinite number of gray bodies corresponding to a given black body at any given temperature.

But a material body can differ from a black body in still another way. Not only may the quantity of energy emitted be different from that of a black body but the quality may also be different. Thus, if a body emitted one-fourth as much red and one-third as much green and one-half as much blue as a black body at the same temperature, it would not correspond to a gray body, but would radiate in a way which we will define as *selective;* that is, it would radiate relatively more energy in one wave-length than in another compared with a black body at the same temperature. This type of selectivity is to be distinguished, at least in degree, from that kind of selective radiation exhibited in the bright line spectra of luminous gases. Now, the question which immediately presents itself on considering the radiation from the various types of incandescent filaments and mantles is this: "Is the high efficiency of the metal filament lamps and the rare earth mantles to be ascribed to a higher working temperature of the luminous substance or to a selectivity in its radiation, such that at a relatively low temperature a preponderance of energy is emitted in the visible spectrum as compared with the radiation from a black body at the same temperature?"

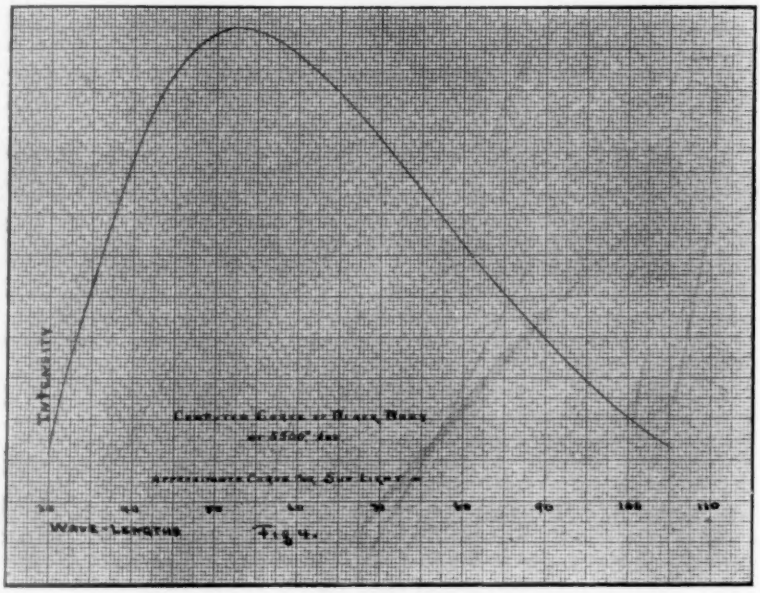
High efficiency is to be obtained by one of three possible ways or by a combination of these. If the radiation is what has been defined as luminescence, the radiated energy might lie principally in the visible spectrum. If this were the case, as is probable in the radiation from the firefly, the efficiency would be very high. As stated previously, however, a discussion of this type of radiation will not be undertaken in the present paper.

Secondly, the high efficiency might be obtained by an excessively high temperature. In a previous diagram (Fig. 3), the energy curves for a black body at various temperatures were given. In every case, the maximum lay well out beyond the visible spectrum. According to Wien's Displacement Law $\lambda_{max} T$ = a constant, where the constant has a value of 2940 for a black body. It is evident, therefore, that in order to bring the wave-length of maximum energy into that part of the visible spectrum where the eye has the maximum sensibility, namely, about $\lambda = 0.56\mu$, the absolute temperature of the black body must

be 2940 divided by 0.56, or approximately 5200°. The temperature, therefore, at which a black body would be most efficient is in the neighborhood of 5000° or 6000° C. The energy curve for such a black body is shown in Fig. 4. This temperature agrees quite closely with the estimated temperature of the sun.

It is interesting to note in this connection that the wave-length of the maximum sensibility in the human eye agrees very

FIG. 4.



closely with the wave-length of maximum energy in the spectrum of the sun.

The third way in which high efficiency may be obtained is through selective radiation in favor of short wave-lengths. If the ratio of the energy emitted in the visible spectrum to that emitted in the infra-red spectrum were twice as great for a given substance at a definite temperature as for a black body at the same temperature, the substance would have double the efficiency of the black body as a luminous radiator, provided the distribution of energy in the visible spectrum of the two were the same.

Before discussing the methods available for determining

whether the high efficiency of metal filament lamps is due to the high temperature at which the filaments operate or to a pronounced selectivity in the radiation of the filaments, it is interesting to note how low the efficiency of even the most efficient light sources is. The ratio of the energy in the visible spectrum to the total energy radiated probably is less than 0.2 even for one of the most efficient lamps we know of, viz., the flaming arc. For incandescent lamps the percentage of energy available for light is still less. In other words perhaps less than 5 per cent. of the energy which is put into a tungsten lamp is radiated in the form of light rays. The other 95 per cent. is radiated in the form of heat rays, of wave-lengths too long to excite the human retina.

In order to show, however, how rapidly the photometric efficiency would increase with comparatively small increases in temperature, in Table I is given the relation between temperature and candlepower of polished platinum at various temperatures as given by Lummer & Kurlbaum. It is thus seen that at a tem-

TABLE I.

Coefficient of change of candlepower with change of temperature for platinum.

$$\frac{I_1}{I_2} = \left(\frac{T_1}{T_2}\right)^X$$

T (absolute)	X	T (absolute)	X
900	30	1400	18
1000	25	1600	15
1100	21	1900	14
1200	19		

perature of 1900° (abs.) or a little below the approximate working temperature of a 3.1 watt carbon lamp, the photometric intensity increases approximately fourteen times as rapidly as the temperature. Thus, a change in temperature of 1 per cent. would cause an increase in candlepower of 14 or 15 per cent. Since for a 1 per cent. change in temperature a change of about 5 per cent. in energy would be required, the increase in efficiency corresponding to an increase of 1 per cent. in temperature would be in the neighborhood of 9 per cent. or 10 per cent. at 1900° C.

At lower temperatures the gain in efficiency would be greater, and at higher temperatures less than that given for 1900° C.

III. METHODS OF STUDYING SELECTIVITY.

About two years ago while at the Bureau of Standards the author developed two photometric methods for giving a positive qualitative criterion as to the relative selectivity of two radiating substances, and applied these methods to a preliminary study of the various incandescent electric lamps then in use. Owing to the enforced interruption of the work consequent upon leaving the Bureau of Standards the investigation was not completed. Most of the essential features of the methods and the preliminary results obtained, however, were described before the American Physical Society,[5] and later presented before the Illuminating Engineering Society.[6] To the best of the author's knowledge the application of the above methods to the various carbon, tantalum, tungsten and osmium lamps gave the first definite data as to the relative selectivity of these various filaments.

In the present paper these new photometric methods will be discussed in more detail than has been published heretofore, and in addition further experimental data will be presented, particularly with reference to the black body and platinum as studied by the same methods as those used with the other radiating substances.

The direct experimental determination of the relation between the energy radiated in different parts of the spectrum and the temperature of the radiating body has only been undertaken for a few substances and over a moderate range of temperature. But by assuming for substances whose radiation curves have not been determined laws and relations which have been found to hold for known sources, much valuable data has been obtained.

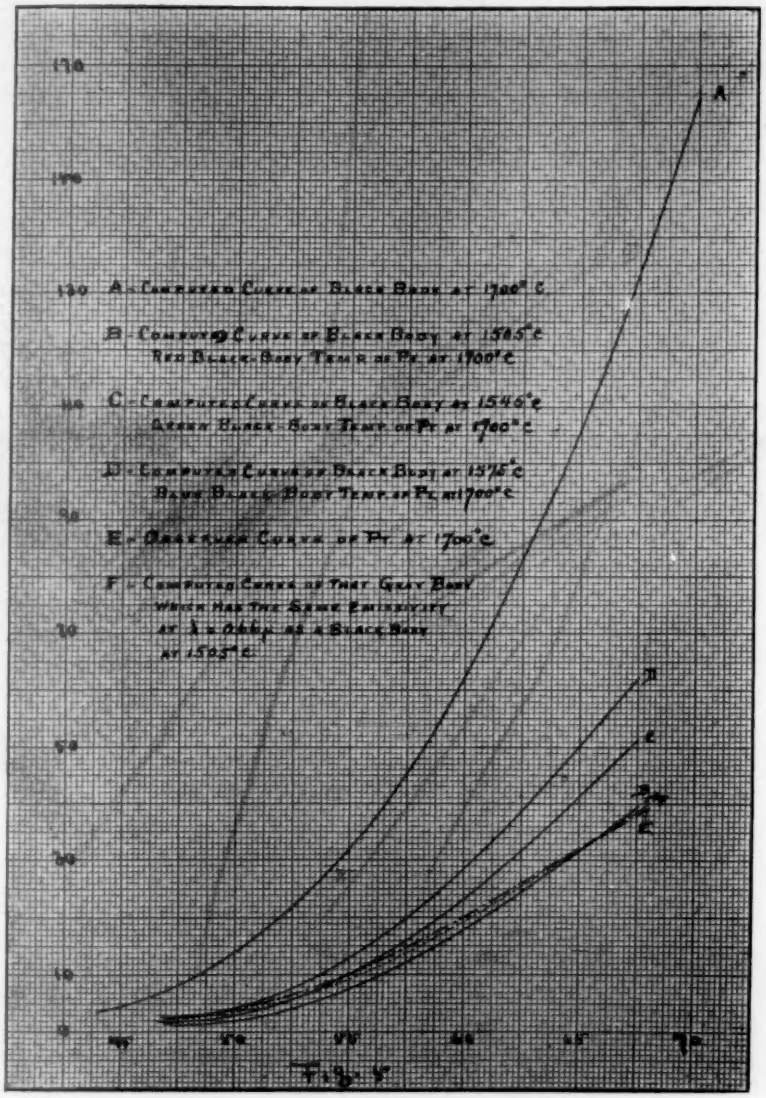
It is now common practice to express high temperatures in terms of the temperature which a black body would have when emitting, per unit area of surface, the same quantity of energy of a given wave-length as the radiating body under investigation, the wave-length employed being taken in the visible spectrum because of the facility with which comparisons of luminous energy can be made photometrically. These so-called black-body temperatures are always lower than the true temperatures of the glowing bodies that are being measured, for the reason that a

black body has a higher emissivity than any other body at the same temperature. Except in the case of those substances for which a direct experimental determination of the relation between the temperature and the energy radiated in different parts of the spectrum has been made, the difference between the black-body temperature and the true temperature can only be estimated on the assumption of empirical relations which have been found to hold for substances having somewhat similar properties.

A method which has recently been employed[7] to determine whether or not the radiation from metals is selective in the sense outlined in a previous paragraph, consists in determining pyrometrically the black body temperature using approximately monochromatic radiation in the red, green and blue regions of the spectrum. If the black-body temperature determined by means of the green radiation is higher than the black-body temperature found by means of the red light, and the "blue black-body temperature" is in turn higher than the "green black-body temperature," it has been argued that the body emits relatively more green than red light, and relatively more blue than green and therefore radiates selectively in favor of the light of shorter wavelengths. Moreover, this property of selection, or "selectivity" as it may be termed, will in all probability extend beyond the visible spectrum so that the energy emitted in the visible spectrum will be relatively larger than that emitted in the infra-red spectrum, as compared with the radiation from a black body at the same temperature.

This method, which is indicative and therefore valuable in the absence of any more exact simple method, is however of limited application, and even within its limited field is subject to criticism. Since the energy in the visible spectrum at all ordinary temperatures is almost negligibly small compared with the total energy radiated, measurements confined entirely to the visible spectrum, such as the ratio of the energy emitted in the red to that emitted in the blue, cannot be trusted to give any quantitative results as to the ratio of the total energy emitted in the visible spectrum to that emitted throughout the entire spectrum. The qualitative conclusion that if relatively more energy is emitted in the blue than in the red, relatively more energy will be emitted in the visible than in the infra-red region of the spectrum, is probably correct for most radiating metals, although it is not

FIG. 5.



necessarily so; but any quantitative extrapolation from measurements in the visible spectrum to conclusions embracing the total radiant energy would scarcely seem justifiable.

Apart from this quantitative limitation to the method it is open to criticism as to the qualitative indication which it gives. It does not necessarily follow that a difference between the red and blue black-body temperatures of a radiating body indicates selectivity in the sense employed in this paper. For a radiating gray body, *i.e.*, one which at a given temperature has the same distribution of energy in the spectrum as a black body at the same temperature but which has a lower emissivity than the black body, the blue black-body temperature would be higher than the red black-body temperature and yet there would be no selectivity.

This can be seen very readily if the ordinary definition of black-body temperature is kept in mind. The red black-body temperature of the gray body is that temperature of the black body at which its emission in the red per unit area of surface, equals that from the gray body at the given temperature. But since the emissivity of the gray body is lower than that of the black body, the red black-body temperature is lower than the true temperature of the gray body. Assuming the emissivity of the gray body to be one-half that of the black body at the same temperature, the latter has to be lowered in temperature until it emits one-half the amount of energy in the red that it emitted at the same true temperature as the gray body. But when the temperature is lowered until the red energy is decreased to one-half, the blue energy is decreased to less than one-half, since a change in temperature produces a change in the shape of the energy curve. Hence, in order that the black body may emit the same amount of energy in the blue as the gray body, *i.e.*, one-half the amount, it would emit at the same true temperature as the gray body, its temperature must be increased somewhat above the red black-body temperature. It is, therefore, evident in this case, that even for a gray body, which by definition is not selective, the blue black-body temperature is higher than the red black-body temperature.

Without some knowledge, therefore, of the emissivity of the radiating body under investigation, it is impossible to draw any definite conclusion from the red, green and blue black-body temperatures in regard to the selectivity of the radiating body, even in the visible spectrum. As an illustration of these principles, the

radiation of platinum may serve as an example, since platinum is one of the few substances whose radiating properties are known. According to Waidner and Burgess when the true temperature of platinum is 1700° C., the red, green and blue black-body temperatures are respectively 1505°, 1545°, 1575°.

In Fig. 5 curve *A* is the curve of the black body at 1700° C. computed from the Planck equation. Curves *B*, *C* and *D* are similarly the computed curves of the black body at 1505°, 1545°, and 1575° C., respectively. Curve *E* is the observed curve for platinum at 1700° and curve *F* is the computed curve of that gray body at 1700° which emits the same amount of energy at $\lambda = 0.66\mu$ as platinum at the same temperature.

A comparison of curves *B* and *F* shows at once that the blue black-body temperature of the gray body would be considerably higher than the red black-body temperature, the actual difference being about 51° C. In other words, of the 70° C. difference between the red and blue black-body temperatures of the platinum, about 51° C., or nearly three-fourths of the difference is due merely to the low emissivity of the platinum, only the remaining 19° C. being due to selectivity. If the blue black-body temperature had been found to be 1556° instead of 1575°, the red black-body temperature still being 1505°, the difference would have been accounted for entirely on the ground of the low emissivity of platinum, and there would have been no indication of selectivity. Any conclusion, therefore, in regard to selectivity of radiation deduced solely from the red, green and blue black-body temperatures of the radiating substance without any knowledge of the emissivity of the body, would seem unwarranted.

Another method which has been employed to indicate selectivity of radiation consists in determining the infra-red energy curve of the substance without any regard to the temperature. Assuming that the laws found for the black body are applicable to other radiating substances, particularly metals, if the values of the constants in the equations are changed, it is possible to compute from the energy curve at any unknown temperature the value of the exponent a which occurs in the Planck equation

$$J = \frac{C_1 \lambda^{-a}}{E^{\frac{C_2}{\lambda T}} - 1}$$

This method, which was first developed and used by Paschen [8] in studying platinum has quite recently been employed by Coblentz [9] in the study of various carbon and metal filament lamps. For a black body $a = 5$, and for platinum it has been found to lie in the neighborhood of 6 or 6.5. The larger the value of a the greater the deviation in this regard from a black body as regards selectivity in favor of shorter wave-lengths. According to the results obtained by Coblentz the various filaments arrange themselves as to increasing values of a in the same general order of selectiveness as has been found by the author by the application of the photometric methods to be described in the following paragraphs.

In regard to this method, it should be said in passing, as has been clearly stated by Coblentz, that the method rests upon the distinct assumption that the radiation from metals can be represented by the same equations as apply to a black body, if the values of the constants are changed to suit each different substance. The very fact that different values of a are found at different temperatures shows that the assumption is not entirely warranted, at least as expressing the energy distribution with varying temperature. However, the method is very valuable in giving a first approximation of the deviation from black-body radiation, and the results obtained by Coblentz in the application of it, are most interesting.

In addition to the above two methods for determining selectivity mention should be made, before passing on to a discussion of the two new photometric methods, of the indications given by the relative reflectivity in different portions of the spectrum.[10] For those metals which have been examined it has been found generally that the reflection coefficient is higher for the longer infra-red waves, and relatively lower for the shorter visible rays, indicating on the basis of Kirchhoff's law a probable selectivity of emission in favor of the shorter wave-lengths.

IV. TWO NEW PHOTOMETRIC METHODS OF STUDYING SELECTIVITY.

In studying the photometric properties of some of the new high efficiency lamps a new method of attacking the problem of determining whether or not the radiation from certain glowing solids is selective, was suggested and tried.

The experiments led to the development of two methods of

determining with some degree of certainty whether a body is radiating selectively. One of the methods may be used even to approximate quantitatively the deviation from black-body radiation as regards the form of the energy curve, and may also be employed to indicate an upper limit to the true temperature of the radiating body, just as the present common method of measuring the black-body temperature fixes a lower limit to the true temperature. Before describing these methods, however, and giving the results of some of the experiments made thus far, it would seem desirable to define a little more exactly than has already been done some of the ideas and terms which will be employed.

As we have seen, there are two distinct ways in which the radiation from two different solid bodies, having continuous spectra, may differ when the bodies are at the same true temperature.

1. The distribution of the energy throughout the spectrum may be the same in the two cases, but the total amounts of energy radiated may be different, *i.e.*, the form of the energy curves may be the same but the heights of the ordinates may be different, the ratio of the ordinate of one curve to that of the other being a constant factor of proportionality for all wave-lengths.

2. Not only may the total energy radiated be different but the distribution of the energy in the spectra may not be the same for the two substances. Thus if we express the radiation from the two bodies at the same temperature by the equations $J_1 = C_1 f_1(\lambda)$ and $J_2 = C_2 f_2(\lambda)$ the two functions $f_1(\lambda)$ and $f_2(\lambda)$ may be identical while the constant coefficients C_1 and C_2 may differ. On the other hand, not only may the constant coefficients, *i.e.*, the emissivities, be different but the forms of the functions may vary also.

In the following discussion we shall adopt the theoretical black body as the standard. Its radiation at any temperature may be expressed by the equation $J_0 = C_0 f_0(\lambda)$. A body which at the same temperature has the same form of radiation curve as the black body, but which radiates less energy in every portion of the spectrum, will be termed a "gray body." Its radiation may be expressed by the equation $J_0^1 = C_0^1 f_0(\lambda)$. This is the ordinarily accepted definition of a gray body. It is evident from the definition that corresponding to a black body at any tempera-

ture there may be theoretically an infinite number of gray bodies, differing only in the constant coefficient C_0^1.

Since the "emissive power" or "emissivity" of a radiating body is usually defined as the total energy radiated outwards per unit area of surface, it is evident that for gray bodies the emissivities are proportional to the coefficients C_0^1.

There are no perfectly black bodies in nature and, so far as I know, none of the materials that have been examined, either directly or indirectly, up to the present time, have been found to have the properties of a theoretical gray body. That is, the emissivity of all substances is lower than that of the black body at the same temperature, and no substance has been found as yet which has the same function $f_0(\lambda)$ giving the same distribution of energy in the spectrum as the black body. We shall define as "selective" in their radiation all bodies for which $f(\lambda)$ is different from that of the black body $f_0(\lambda)$ at the same temperature. As stated above, all substances that have been investigated so far are more or less selective in their radiation. A gray body does not radiate selectively.

We seek, first, a positive criterion of selectivity; that is, putting aside for the present the question as to what extent high efficiency is to be attributed to the high temperature at which the filament is operated, and to what extent to the selectivity of its radiation, we want to know, first, whether there is any simple method of determining positively that the radiation from one body is qualitatively different from the radiation of another body at the same temperature.

In order to understand one of the methods which have recently been employed to determine selectivity, let us suppose that there are two radiating bodies at the same temperature, one of them black, the other gray. According to the definition of a gray body which has been given, the quality of the energy radiated is identical with that from the black body at the same temperature, but the emissivity is less than that of the black body. The shape of the energy curves of these two bodies, therefore, at the same temperature, would be identical, and if there were no means of determining the absolute intensity of the radiation, it would be impossible to distinguish them by any method which would give only the relative distribution in different parts of the spectrum, for if the black body had twice as much energy in the red as it

had in the blue or three times as much energy in some particular wave-length of the infra-red as it had in some particular wave-length in the visible spectrum so would the gray body show the same proportions of energy in different parts of the spectrum. In other words, if the energy curves were plotted to the proper scales the two curves would be co-incident throughout the entire spectrum.

If now the temperature of one of the bodies was changed slightly, this condition would no longer exist, for the shape of the curves would be different. Conversely, given the black body at a definite temperature, if the temperature of the gray body is varied until the distribution of energy in the spectrum of the gray body is identical with the distribution of energy in the spectrum of the black body, the temperature of the gray body would then be identical with that of the black body.

Now it is possible by means of a spectrophotometer to bring the two energy curves into agreement. Thus one would determine with the spectrophotometer the distribution of energy in the visible spectrum of the black body at some definite temperature. The temperature of the gray body would then be varied until the distribution of energy in its visible spectrum is identical with that of the black body. If the two curves agree in the visible spectrum, they must agree throughout the entire spectrum, and the two bodies must be at the same temperature. If the curves agree throughout the entire spectrum the ratio of the energy in the visible region of the spectrum to the total energy radiated must be the same in the two cases even though the absolute intensity of the radiation is less for the gray body than for the black body.

Suppose now that these two bodies,—the black body and the gray body,—were in the forms of filaments mounted in exhausted bulbs, and, that keeping constant the voltage of one lamp which we will say contains the black filament, we vary the voltage of the other lamp (supposedly containing the gray filament) until as determined spectrophotometrically, the distribution of the energy in the visible spectra of the two is the same. Then, as pointed out just above, the ratio of the energy in the visible spectrum to the total energy radiated, should be the same in the two cases.

Now, it is very easy to compare the energy radiated in the visible spectrum by determining the total luminous flux of the

two sources. There will be no physiological complications because, by hypothesis, the distribution of energy in the visible spectrum is the same in the two cases. Moreover, it is very easy to determine with moderate accuracy the total energy radiated by merely measuring the energy supplied to the lamps. Since the filaments are mounted in exhausted bulbs there will be no convection; and since, as ordinarily mounted, there is very little conduction of energy away by the leading-in and anchor wires, it follows that practically all of the energy supplied to the lamp is given up by the lamp in the form of radiant energy.[11] If then one of the filaments has the characteristics of a black body and the other filament has the characteristics of a gray body at the same temperature, the ratio of the energy in the visible spectrum (total luminous flux) to the total energy radiated (energy supplied to the lamp) should be the same in the two cases; that is, the two lamps should have the same lumens per watt. It must follow, therefore, that if a filament of unknown radiating properties is regulated in voltage until it shows the same relative distribution of energy in the visible spectrum as a second filament which has the characteristics of a black body, and if under these conditions the lumens per watt of the two lamps are the same, we may conclude with reasonable certainty that the filament with unknown radiating properties has the characteristics of a black or a gray body,—we cannot tell which. Conversely, if under this condition of equivalent distribution in the visible spectrum, the lumens per watt of the two filaments are different, it must follow that the filament of unknown radiating properties does not have the characteristics of a gray or black body. It must, therefore, be selective.

So far no means have been adduced of determining how selective a body is, because the moment a difference in the shapes of the total energy curves is encountered, it can no longer be argued that when the curves agree in the visible spectrum the two bodies are at the same temperature, and unless there is definite knowledge in regard to the relative temperatures of the two bodies it is impossible to draw quantitative conclusions as to the amount of the selectivity of the selectively radiating lamp.

The above method, therefore, gives a positive qualitative criterion for studying the relative selectivity of materials that can be mounted in the form of filaments in exhausted bulbs.

But there is another photometric method of establishing a criterion of selectivity; in fact, this second method is the one which was first used, in the early part of the investigation. Let us go back to the original supposition of two radiating bodies, one black and the other gray. As stated before, when these two bodies are at the same true temperature, their energy curves will be identical except for the absolute height of the ordinates, and the ratio of the energy in the visible spectrum to the total energy radiated will be the same in the two cases.

Suppose now, the temperature of each body is raised the same amount so that they are again at the same temperature, the temperature however being higher than in the previous case. The shapes of the two energy curves should again be exactly identical, and therefore, the ratio of the energy in the visible spectrum to the total energy radiated should be the same. This ratio, however, will be greater than it was when the two bodies were at a lower temperature.

Since the ratio of energy in the visible spectrum to the total energy radiated is the same for the black and the gray bodies at the low temperature and is the same,—though higher than before,—for the black and the gray bodies at the higher temperature, it must follow that the increase in the ratio of the visible energy to the total energy corresponding to a given increase in temperature must be the same for the two bodies.

Suppose now, as before, that the black and the gray bodies are represented by filaments mounted in exhausted bulbs, and that holding the voltage of the black filament constant we vary the voltage of the gray filament until, as determined spectrophotometrically, the two lamps have the same spectral distribution in the visible spectrum. The two bodies will then probably be at the same true temperature; their energy curves will be identical throughout; and the lumen per watt for the two will be the same.

Suppose now that the temperature of the black filament is raised by increasing the applied voltage, and that again the voltage of the gray filament is varied until its energy curve in the visible spectrum agrees with that of the black filament. The two filaments will then be at the same temperature, higher, however, than before; their energy curves will be identical throughout the entire spectrum; and the lumens per watt will be exactly the same. The value of the lumens per watt, however, will be higher, that is,

the efficiency will be higher than it was when the two filaments were at the lower temperatures, but since the lumens per watt for the two filaments were the same at the lower temperature and are the same at the higher temperature, it follows that the change in lumens per watt for the gray filament must be the same as the change for the black filament. Suppose, therefore, we had a filament with unknown characteristics and compared it with a filament having the characteristics of a black body. Thus, suppose we brought the two filaments spectrophotometrically to the same distribution of energy in the visible spectrum and measured the lumens per watt, and then raising the temperature of the black filament, again brought them to the same distribution of energy in the visible spectrum. If we found the change in lumens per watt for the two filaments to be the same, we would conclude that the filament with unknown radiating properties was a gray or a black body.

However, this method, as explained thus far, involves all the measurements of the first method and is really identical with it; but this second method permits of very considerable simplification.

It is not necessary to bring the body with unknown radiating properties to the same distribution of energy in the visible spectrum as the black body at more than one temperature. For if the two bodies had the same distribution of energy in the visible spectrum, and the total energy radiated, that is, the total energy supplied to the two filaments, was increased by the same amount, the filament of unknown radiating properties, if either gray or black, would show the same change in lumens per watt, *i.e.*, the same percentage change in total flux, or mean spherical candlepower, as the black body, whether or not an investigation was made to see that the distribution of energy in the visible spectra of the two was the same at the higher temperature. As a matter of fact, it would be the same. But if the filament with unknown radiating properties were not gray or black, the change in mean spherical candlepower corresponding to a definite change in energy supplied to the filament would not be the same in the two cases. And, conversely, if on measurement it was found not to be the same, one might conclude with assurance, that the body with unknown radiating properties radiates selectively.

It is unnecessary, however, to measure the mean spherical

candlepower, a candlepower determination in one direction being sufficient. We are only interested in the change in candlepower corresponding to a definite change in energy supplied, and the change in candlepower in any one direction will be proportional to the change in the mean spherical candlepower. Thus, suppose two filaments are brought to the same distribution of energy in the visible spectrum and a determination is made for each filament of the percentage change in candlepower in some one direction corresponding to a change of 1 per cent. in the watts supplied to the lamp. If it is found that the percentage change of candlepower is the same in the two cases, it may be concluded that the filament with unknown radiating properties has the characteristics of a gray or black body. If the change in candlepower corresponding to 1 per cent. change in energy is different for the two filaments it may be concluded positively that the filament with unknown radiating properties radiates selectively.

This coefficient of change in candlepower corresponding to 1 per cent. change in watts has very frequently been determined for filaments of different materials, but a comparison of the resultant coefficients when the two filaments have the same distribution of energy in the visible spectrum, and the deduction from the results as to the selectivity indicated by a comparison of the coefficients under this condition have never been made. This, then, constitutes a second qualitative method of determining positively whether or not one filament radiates selectively as compared with the radiation from a second filament.

In both methods the starting point has consisted in bringing the two filaments to the same distribution of energy in the visible spectrum by means of spectrophotometric measurements. The same result can be accomplished, however, in a very much simpler manner. The eye is very sensitive to slight differences in tint. If, therefore, a lamp is burned at a definite voltage on one side of a Lummer–Brodhun contrast photometer screen, and the voltage of a second lamp placed on the other side of the screen is varied, one can determine with considerable accuracy when the second lamp has the same distribution of energy in the visible spectrum as the first lamp by varying the voltage until the two sides of the photometer screen appear to have the same tint. In fact, this method of bringing the two lamps to the same distribution of

energy in the visible spectrum is perhaps more sensitive than the spectrophotometric method, and yields results in close agreement with the latter so far as our measurements indicate. It is conceivable, of course, that two lamps might have the same color, and yet show different spectral distributions. Such a case has not yet been observed. On the other hand it has been found that in certain cases, *e.g.*, with the osmium *vs.* the carbon lamp, it is impossible to obtain exact color matches, although the spectrophotometric curves differ by an amount so small that the difference might well be ascribed to observational error. It is quite probable that if any two substances, when brought to approximately the same distribution of energy in the visible spectrum, show evidences of different energy distribution in the infra-red, there are slight differences also in the visible region. These differences, however, are so small for the substances examined, that in no case was such a difference distinctly evident from the spectrophotometric measurements, and only in the case of osmium was the difference in integral color sufficiently pronounced to be noticeable.

It is quite a simple matter, therefore, to compare the relative selectivity of two lamp filaments by either of the two methods given above. Thus, subjecting one filament to some definite voltage, we determine the voltage of the other filament at which its light matches in color that from the first filament. Then, according to the first method, we measure the total luminous flux and the watts supplied to each lamp, and compute the lumens per watt. If the two values are the same, the lamps are relatively not selective. If all the lamps are measured in terms of some one carbon lamp as a standard, their relative selectiveness can be determined. Carbon is chosen as the standard because it probably approaches most nearly of all to a black body.

The final step would then be to compare this standard carbon lamp directly against a black body. In this way the results are expressed in terms of a standard which can be reproduced with moderate accuracy. Moreover, whatever relative selectivity between different material substances may be found, it is only when the results are expressed in terms of a black body that any positive knowledge as to absolute selectivity is obtained. Although up to the present time it has not been feasible to measure the lumens

per watt from a black body, several determinations have been made of the change in candlepower of a black body for 1 per cent. change in total energy radiated when the black body was at a color match with the various filaments. A more detailed statement of the method employed in the use of the black body will be given below.

In addition to the black body, platinum was also studied since it has been customary in the literature of radiation to refer other substances to these two as standards, platinum usually being considered as departing farthest from true black body radiation of all metals studied.

V. PROCEDURE AND RESULTS ON VARIOUS METALS AND CARBON.

We desired to compare the radiating properties of the filaments at different temperatures, but in order to avoid at the beginning of the investigation any direct temperature measurements, we selected as our arbitrary temperatures those temperatures which a particular carbon filament had at 3 definite voltages over a considerable range of voltage. Thus, we compared the radiating properties of the various filaments when they were at a color match with the standard lamp at 75 volts; again, when they were at a color match with the standard lamp at 100 volts; again, when they were at a color match with the standard lamp at 125 volts. Finally, it was the intention to make a comparison, if possible, when they were at a color match with the standard lamp at 150 volts but these measurements have not been completed as yet. The standard lamp was a treated carbon filament of about 3.5 watts per candle at 110 volts.

The method, therefore, was to determine for each lamp the voltage at which it matched in color the standard lamp at 75 volts, 100 volts and 125 volts successively, then burning these lamps at the determined voltages to measure the coefficient of change in candlepower corresponding to 1 per cent. change in watts, and to measure the lumens per watt for each lamp. The results are given in Tables II to IV, and include measurements on lamps of untreated, flashed and metallized carbon, tantalum, tungsten, osmium, platinum and "helion" filaments, and also on the electrically heated black body. The types of lamps used were as follows:

4 Untreated carbon lamps	16 cp., 110 volts, 4	w.p.c.
3 Flashed carbon lamps	16 cp., 110 volts, 3.5	w.p.c.
4 Metallized carbon lamps	20 cp., 110 volts, 2.5	w.p.c.
4 Tantalum lamps	20 cp., 110 volts, 2.0	w.p.c.
2 Tungsten lamps	48 cp., 110 volts, 1.25	w.p.c.
1 Tungsten lamp	32 cp., 110 volts, 1.25	w.p.c.
2 Osmium lamps	32 cp., 55 volts, 1.50	w.p.c.
3 "Helion" lamps	(odd voltages and candle powers)	

A number of special platinum lamps of odd voltages and candlepowers.

The osmium lamps were obtained through the courtesy of Mr. Mason, of the Welsbach Company. The "Helion" lamps were kindly furnished by Messrs. Parker and Clark, the inventors. The platinum lamps were obtained from different sources but contained filaments in every case of Heraeus c.p. platinum wire. The first two lamps measured while at the Bureau of Standards were kindly furnished by Mr. J. W. Howell of the General Electric Co. Subsequently a number of lamps of special forms have been made through the courtesy of Messrs. J. E. Randall and H. F. Schaedel, of the National Electric Lamp Association. Other special lamps are being constructed in order that further measurements may be made, including, it is hoped, data on lumens per watt as well as on the coefficient of change of candlepower with change of energy.

The black body measurements were made possible through the courtesy of Drs. Waidner, Burgess and Coblentz, of the Bureau of Standards, who placed two different electrically heated black bodies [12] at the disposal of the author and very kindly undertook personally to make the necessary temperature measurements.

(To be continued.)

THE MECHANICAL PRINCIPLES OF BRENNAN'S MONO-RAIL CAR.*

BY

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[This paper is an endeavor to develop by brief elementary methods the mathematics and physics of the gyroscope, and their application to Brennan's Mono-rail Car. The writer is of the opinion that anyone who is familiar with elementary mechanics will be able to understand this paper and use the equations in practical design. The relations developed are so simple and the proof so plain that it is hoped that they will assist in perfecting the design of various sorts of balancing devices by revealing clearly the secret of the mechanical principles involved in them. Outline: (1) Account of trials of Brennan car. (2) Analogy of centrifugal and gyroscopic action. (3) Equilibrium of the car under unbalanced loads. (4) Equilibrium of the car running on a curve. (5) Limits of stability of the car. (6) Nutation during the establishment of equilibrium.]

EARLY in 1907, Louis Brennan, the inventor of the Brennan torpedo, exhibited before the Royal Society of England a working-model of a mono-rail car which was able to preserve its equilibrium perfectly while in motion or at rest, while travelling around sharp curves, while running on a swinging cable, or subjected to sudden shifting of load from side to side. The apparatus by which automatic balance is preserved in this remarkable manner consists of a pair of heavy fly-wheels mounted on the car which rotate at high speed in opposite directions about axes

* Since the time when Foucault, in 1852, applied the gyroscope to demonstrate ocularly the rotation of the earth on its axis and the precessional motion of the latter, various efforts have been made to utilize gyroscopic action for practical purposes. The first, and until within recent years, the only attempt in this direction of which there is any authentic record, is that of Prof. Piazzi Smyth who, in 1856, devised a telescope stand provided with a gyroscopic apparatus calculated to maintain it level while supported on the constantly changing plane of the deck of a vessel at sea. The apparatus was tested by Prof. Smyth on board a naval vessel in the course of a sea voyage and, according to authoritative reports of the experiment, was found to serve its purpose. It appears, however, that the mechanism was too complicated for regular use. About 1897, an Austrian engineer, M. Obry, applied the principle of the gyroscope, namely the tendency of the fast-revolving wheel to maintain its given direction in space, for the purpose of automatically steering a torpedo. His invention was subsequently perfected and successfully applied by the Whitehead Torpedo

transverse to the car. The gyroscopic effect of these rotating wheels prevents the car from toppling over, somewhat as a top is prevented from falling while spinning.

On November 11, 1909, a further demonstration was given with a full-sized car in the War Office grounds of Great Britain, at Chatham, England. Accounts state that the car which was there operated with entire success was 40 feet long, 10 feet wide and 13 feet high, and weighed 22 tons. The car ran on a single rail around a circular track 220 yards in circumference at a speed of 25 miles an hour, carrying a load of 40 passengers on its platform where they had entire freedom of movement. The balance was automatically preserved by the action of two gyroscopes 3½ feet in diameter, weighing ¾ of a ton each, and revolving at the rate of 3000 revolutions per minute. The gyroscopes run in a vacuum to reduce friction. A gasolene engine was used to propel the car and keep up the speed of the gyroscopes.

It is reported that a German mono-rail car is soon to be exhibited embodying the same principle, of which the motive power will be electrical. Indeed, synchronous motors would apparently furnish an ideal means of keeping the two gyroscopes in step with each other, and the trolley would be a natural means of propulsion for such a car.

Models to illustrate the working of the Brennan car constructed in this country from the designs of Professors Crew and Tatnall, Northwestern University, are accessible to the public,

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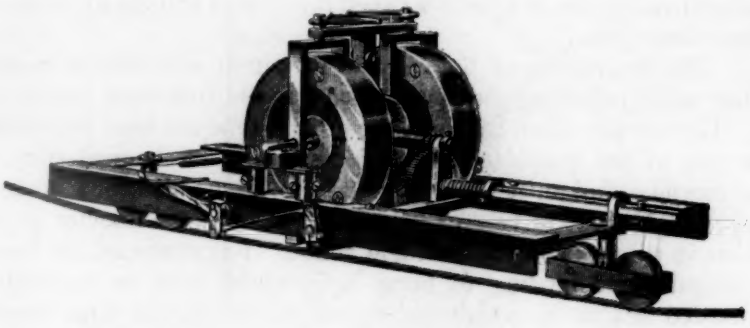
Co. In 1904, Herr Otto Schlick brought out before the British Institute of Naval Architects a gyroscopic mechanism which was subsequently developed into an apparatus to prevent the rolling of ships at sea. This appliance was successfully demonstrated in 1906 in experiments on a German torpedo-boat, and in 1908 was practically applied on an English steamship by the Neptune Works at Newcastle. About the same time, according to report by U. S. Consul-General Wright, from Munich, April, 1905, another German inventor, Dr. Anschütz-Kämpfe, produced an apparatus in which the gyroscopic principle of maintenance of direction in space is applied as a compass. Experiments with this instrument on board a German warship appear to have proven it capable of replacing the magnetic needle under conditions wherein the latter is unreliable. The latest practical application of the gyroscope as represented by the Mono-rail Car of Mr. Louis Brennan was the subject of a lecture by Prof. W. S. Franklin of Lehigh University before the Institute at its stated meeting in February last and the following paper affords a lucid demonstration of the principle involved.—ED.

as shown in Fig. 1. It is said by the makers, to embody the following essential points, which are here quoted from their published statement, with a few emendations and amplifications:

A. The use of two gyroscopes or fly-wheels, mounted side by side in frames, as shown in Fig. 1, and rotating about a horizontal axis in opposite directions with equal speed. The precessional couple about an axis lengthwise of the car, due to the turning of the car about a vertical axis in rounding a curve, is equal and opposite for the two gyroscopes, hence the upsetting torque arising from this source vanishes.

B. The employment of a pair of shelves or plates as friction surfaces, attached to the sides of the car, one on each side. When

FIG. 1.



the car begins to tip over to one side, one of these shelves is raised and begins to press against the rotating end of the gyroscope axle, which projects over it. This pressure causes the gyroscope to turn, or precess, about a vertical axis. The frame of the second gyroscope is geared to that of the first in such a way that it is forced to turn equally in the opposite direction, as shown at the top of Fig. 1. The axle, on account of friction on the shelf along which it tries to roll has a force exerted on it whose moment tends to increase the precession. The moment of this frictional force about a vertical axis has the effect, not to increase the precession already taking place, but instead, to cause precession about the longitudinal axis. The opposite moments acting on oppositely rotating gyroscopes conspire to cause precession in the same direction about the longitudinal

axis of the car. This rights the car and tips it slightly to the other side, to be brought back again by the second shelf. The centre of gravity of the whole car is thus kept oscillating very slightly on either side of the line of upward thrust of the rail.

C. The use of a second pair of shelves next to the first pair, each engaging an idle roller whose friction is negligible, attached to the gyroscope frame, and serving to return the frame, after displacement, to its normal position, transverse to the car.

D. The use of a single central frame in which both the gyroscope frames turn, or precess, which is itself solidly mounted on an axis lengthwise of the car, and on the same level with the gyroscope axes, so that this frame and the gyroscopes it carries can together tip to the right or left with reference to the car, or the car can be tipped with reference to them, to an amount determined by the clearance between the shelves and the gyroscope axes over them.

This description of the car and its action will become more clear after following the developments in the following pages.

Gyroscopic action has up to the present time not been regarded as one of the available devices for securing mechanical effects in machine design, but rather as one to be avoided, and where unavoidable, one to be guarded against in the same manner as is done in most cases of centrifugal action. For example, the centrifugal force tending to burst a fly-wheel must be carefully guarded against in design and operation, but on the other hand centrifugal action is boldly made use of as the essential element of design of engine and turbine governors of all sorts. In the same way the gyroscopic action of armatures on shipboard must be carefully provided against. But as appears from this invention, we must, hereafter, be prepared to make use of the peculiar properties of gyroscopic action to produce mechanical effects that are otherwise unattainable.

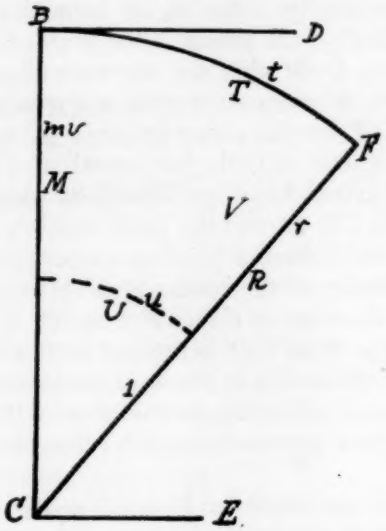
To this end, it is the purpose of the present paper to set forth the principles of gyroscopic action in general and, in particular, to describe their application to the mono-rail car, in such an elementary and geometrical form as to make the action intelligible and calculable without recourse to complicated mathematics. This may be done most readily by help of the close analogy, or say identity, which exists between the mathematics of centrifugal action and that of gyroscopic action.

This we now proceed to develop. Suppose a body of mass m revolve in the horizontal plane of Fig. 2 about C to which it is attached by a string of length r. If the linear velocity of m along the circle of radius be v, then it is well known that the tension of the string

$$t = \frac{mv^2}{r} = mu^2r = mvu \qquad (1)$$

in which the deviating (or centrifugal) force t continually draws m away from the straight path it would otherwise follow along

FIG. 2.



a tangent to the circle, and u is the angular velocity of revolution, *i.e.*, the linear velocity of a point on r at the distance of unity from C.

Equation (1) may be written in the form

$$1 : mv :: u : t \qquad (2$$

from which it appears that if the distance $r = CB = CF$ be taken on some arbitrary scale to represent graphically the numerical amount of the momentum mv, and it be laid off at right angles to the direction of the momentum along BF, viz., at successive instants along r in its successive positions, then

on the same scale the length of the arc BF at right angles to the successive positions of r measures the impulse of the deviating force, which is numerically the same as the tension t, the tension at any instant being at right angles to the arc, just as mv at any instant is at right angles to the position of r at that instant.

The elementary considerations by which equation (1) is established will not be here developed, as they may be found in any treatise on the mechanics of motion. Equations (1) and (2) express a necessary relationship of the mechanical and physical quantities concerned. For example, the tension t can be increased only by some suitable change in one of the other quantities, such as using either a greater mass m, or imparting to it a higher velocity v, or making r, the radius of the circle of motion, smaller.

Now in order to develop the corresponding equations for gyroscopic action, let us assume that a gyroscope or fly-wheel whose moment of inertia about its axis of rotation is M is rotating with its axis initially horizontal at CB. It is to be noticed that the actual linear motion of its particles in space is at right angles to CB, as was the linear motion of m previously treated. Let the axis have a point of support at C only, and let the centre of gravity of the total weight W supported at C be situated at B, a distance of $CB = R$ from C, so that it requires a couple of torque $T = WR$, combined with a vertical force at $C = W$ (the weight acting at B) in order to keep W from falling. Let the gyroscopic wheel revolve about CB with an angular velocity V, then its constant angular momentum about CB is MV.

On some arbitrary scale let $R = CB = CF$ be taken to represent graphically the numerical amount of the angular momentum MV. On the same scale the arc $BF = T$ may be taken to represent the deviating angular impulse of the torque T, which is numerically the same as the torque T. This angular impulse continuously generated by W at right angles to the angular momentum MV is to be compounded with it in precisely the same manner that the linear impulse generated by the deviating tension t is compounded with the linear momentum mv, instant by instant, during its generation, in order to produce a uniform deviation in a circle.

The torque T due to the weight W at B acts always at right angles to the axis of the angular momentum MV just as the

tension t at B acts always at right angles to the linear momentum mv, hence MV and T must be compounded according to the same laws as mv and t.

Therefore

$$1 : MV :: V : T \tag{3}$$

or

$$T = MVU = \frac{MV^2}{R} = MU^2R \tag{4}$$

in which U is the angular velocity of R about C in the horizontal plane and the gyroscope is said to precess or turn at the rate U. The apparently paradoxical action of the gyroscope consists in this, that while rotating about one axis a torque acting on it apparently tending to turn it about a second axis at right angles to the first, actually does turn it about a third axis at right angles to the other two, and this is its only effect.

Equation (4) may also be written:

$$W = \frac{T}{R} = \frac{MVU}{R} = \frac{MV^2}{R^2} = MU^2 \tag{5}$$

These equations (3), (4) and (5) express physical relations that must necessarily exist in gyroscopic action during dynamic stability of motion. They show, for example, that a decrease in the rotary velocity V through friction or otherwise would require a more rapid precession U in order to support the given weight W, a fact readily observed; or again, V remaining unchanged, any increase in W will produce a corresponding increase in U, as appears at once experimentally.

In order to comprehend clearly how the direction of precession is related to the rotation and torque, suppose the rotation of the gyroscopes appear clockwise to an observer looking from B towards C, then to an observer looking from D to B gravity tends to make the axis BC rotate about C, so that the impulse of T is clockwise also, about a horizontal axis EC, which is parallel to the tangent at B, to an observer looking from E to C.

This angular impulse of T, generated instant by instant, is continuously compounded with the constant angular momentum MV. Since it acts always at right angles to MV, its effect is not to increase or decrease MV but solely to change its direction, so that the axis of rotation R is steadily moved forward to successive positions intermediate between BC and EC and thus at

the end of a unit of time it occupies some position CF. It will evidently move to a position between BC and EC whenever both are clockwise, which will therefore also make the precession U clockwise when the observer looks down on C.

Careful attention should be given to the relative directions of rotation just indicated for the three quantities T U V, which are arranged in alphabetical order, are mutually at right angles, and are so situated with respect to each other that they follow each other cyclically clockwise to an observer looking towards C from any point in the solid angle between them, and they each indicate clockwise rotation to an observer looking along either of them towards C. Considered in this way it is not difficult to analyze gyroscopic effects into clockwise actions, since every rotation is clockwise for one aspect or the other. It further appears that a force applied at right angles to W in an attempt forcibly to increase or decrease the precession U would fail to do so, but would instead produce a precession in a vertical plane, thereby causing W to rise or fall according to the above rule. It would greatly assist the student of the mono-rail car to use a pair of graphical models made of corks into which three pins of different kinds are stuck at right angles, one along the axis of the cork to represent V or MV, and two others at right angles for T and U respectively, placed in the order mentioned above.

In all this discussion of centrifugal action and gyroscopic action it will be noticed that we have carefully confined our attention to the relation between the external applied forces and the motions ensuing, and have not considered the equal and opposite internal forces that are developed in the form of reactions in equilibrium with the applied forces. This has been done for the sake of simplicity and to avoid all possible confusion as to cyclic order, etc. Its correctness as a method can no more be questioned than can its application to the case of motion of a falling body where the external force of gravitation acts and motion ensues, and no regard need be had to the fact that by its inertia the body develops an internal reaction equal and opposed to the force of gravitation.

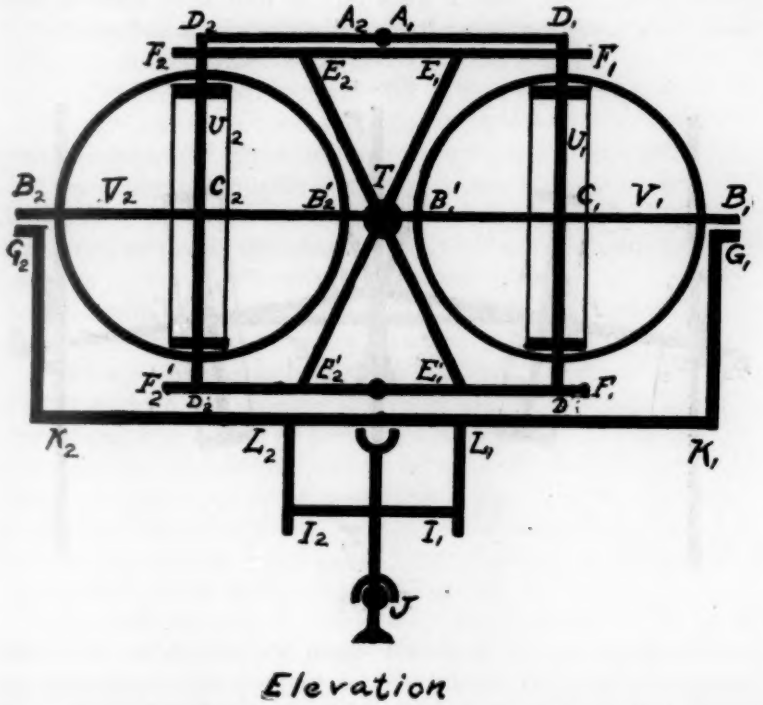
A vertical transverse section of the gyroscopic equilibrating parts of Brennan's mono-rail car may be represented in diagram

as in Fig. 3, and in horizontal section or ground plan in Fig. 4, in which the same letters refer, so far as possible to corresponding parts in both figures at once.

The arrangement consists of a pair of gyroscopes revolving on horizontal axes B_1C_1, B_2C_2 at the same speed $V_1 = V_2$ in opposite directions, so that a spectator looking along either axis from B_1 to C_1, or B_2 to C_2 will see the wheels rotating clockwise.

This speed is to be maintained by applying so much power

FIG. 3.



Elevation

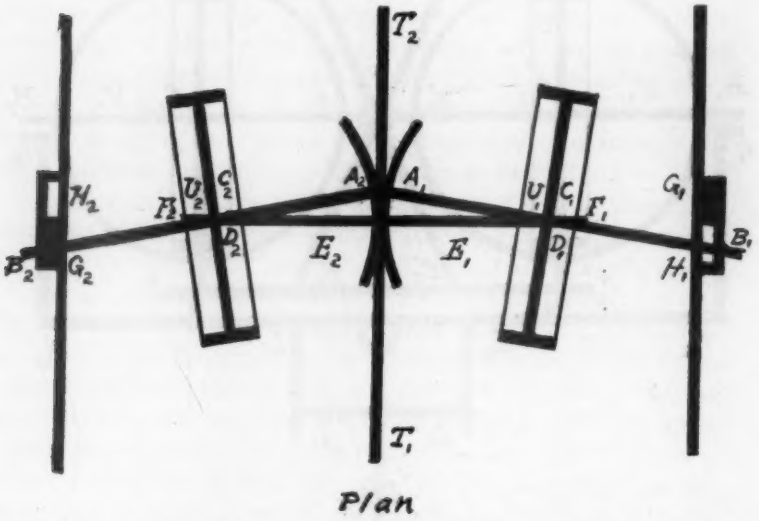
as may be necessary to overcome friction, preferably by synchronous motors upon the axes BC. The axes BB are carried in bearings in the vertical frames which are shown in Fig. 3 in the form of circular rings. These rings swing about vertical axes $D_1D'_1$, $D_2D'_2$ which in turn are carried in bearings in a vertical framework EF rigidly fixed to an axle TT. The axle TT which lies lengthwise of the car, which is represented in

cross section by *GKL*, is solidly supported by bearings in the car, vertically above the rail *J* and the car wheel, which last revolves about the horizontal axis I_1I_2.

In Fig. 4 the gyroscopes are represented in a position which they would assume after having suffered a small deviation from their mean normal position (in which *BB* and *TT* are mutually at right angles) such as would occur after a small precessional rotation had taken place.

The gyroscopes are kept in step with each other in their motion about their vertical axes *DD* as well as in their motion about their horizontal axes *BB*, so that their rate and amount of

FIG. 4.



precession about *DD* is always equal and opposite. This first result is effected by means of two toothed sectors A_1 and A_2, which engage each other and which are rigidly attached to D_1 and D_2 respectively by arms *AD* which may be regarded as right angled prolongations of D_1 and D_2. Thus the arms *AD* turn with the rings about the vertical axes *DD* and we thus have $U_1 = -U_2$, as well as $V_1 = -V_2$, so that the rates of precession are equal and opposite as well as the rotary velocities.

The fact that both gyroscopes are carried by the rigid frame *EF* requires, however, that any turning of the gyroscopes about the axis T_1T_2 which is perpendicular to both *BB* and *DD*, shall

be the same for both gyroscopes and in the same direction, not in opposite directions. Let this condition be expressed by the equation $U'_1 = U'_2$, in which U'_1 and U'_2 are precessions about T_1T_2.

In Fig. 3 the car is represented as in perfect balance in a horizontal position, but this is not the case in Fig. 4. Suppose an unbalanced load be placed upon the right side of the car between L_1 and K_1. That would tip the car and bring the plate at G_2 into contact with the rotating prolongation of the axis B_2C_2 at B_2.

This plate consists of two parts, a rough part G_2 intended to act as a friction brake on B_2 and a smooth part H_2 on which the axis B_2 can rotate without friction. As soon as this plate exerts an upward pressure upon the axis at B_2 the unbalanced load is transmitted to the gyroscopes in the form of a torque about T_1T_2 and the action is the same as though a pair of equal weights were hung upon the right hand half of each gyroscopic axis whose combined torque is the same as that of the unbalanced load. As already explained the effect produced upon the gyroscopes is not to cause any revolution about the axes about which T acts, but instead to produce precession about the vertical axes DD.

The right hand gyroscope then has its three clockwise actions TUV situated as already described in our treatment of the gyroscope, Fig. 2, and its precession is clockwise as we look upon it from above as represented in Fig. 4; while the left hand gyroscope having a clockwise rotation V_2 observed from B_2 and a clockwise T looking from T_1 to A_2 must have a clockwise precession U_2 viewed from below, thus producing the precession represented in the left gyroscope, Fig. 4.

The sectors A_1A_2 are therefore unnecessary so far as this action is concerned. But it is otherwise with respect to the action of the friction plate G_2. For, as the axis at B_2 rolls upon G_2 a horizontal force is exerted on B_2 which exerts a torque T'_2 say, about the vertical axis D'_2D_2, clockwise when viewed from below, in its effort to increase the rate of precession U_1. This it is unable to change. Instead of causing an increase in the precession U, the torque T'_2 will cause a precession U'_2 about an axis at right angles both to MV_2 and U'_2, *i.e.*, about $T_1\ T_2$.

Let T' designate the torque of any couple produced by fric-

tion tending to turn either gyroscope or both about a vertical axis in a clockwise direction, then by equation (4),

$$T' = MVU' \tag{6}$$

gives the value of U', the precessional angular velocity produced about the horizontal axis T_1T_2, to right the car and bring its centre of gravity to a position vertically over the rail. That this statement is correct is evident upon considering the necessary relative position of $T'_2U'_2V_2$ for the left gyroscope, since they may be regarded as acting independently of TUV previously treated. The graphical model will show that the precession U'_2 is such as to right the car by giving it a precession opposite to the torque T of the unbalanced load, which precession will diminish and cease as the car is righted.

We have here considered the left gyroscope as if it alone were effective in righting the car. In fact both gyroscopes conspire to produce the same effect, for one-half of the torque T' is transmitted by the toothed sectors AA to the right gyroscope in which T' is, therefore, clockwise seen from above and U'_1 is clockwise looking from T_2 to A_1. This action therefore brings a mechanical stress on the toothed sectors to transmit part of T' from one gyroscope to the other, and in equation (6) M is the sum of the moments of inertia of both gyroscopes.

It is evident since the car as shown in Fig. 3 is in unstable equilibrium that left to itself it must immediately incline to the one side or the other. We have just shown how the gyroscopes act in case of an unbalanced load to return the car to the position of unstable equilibrium for car and load together.

Suppose now that the car tips still further in the direction in which the gyroscopes have been operating to right it, so that from unstable equilibrium it begins to tip over and down to the left, while the axes of the gyroscopes have stopped in the position shown in Fig. 4, as they would, since there is no unbalanced load to maintain precession. The first effect of this initial inclination to the left would be to bring the smooth plate H_1 into contact with the right axis at B_1. Whatever might be the force which H_1 exerted to press B_1 upward, its only effect would be to produce a precession about the vertical axes DD in the opposite direction from that which was produced when G_2 pressed B_2 upward. This precession about DD will serve to restore the

axes BB of both gyroscopes to their normal positions transverse to T_1T_2, but it will not be accompanied by any precession about T_1T_2 until B_1 reaches G_1.

The effect of the plates G and H combined with the very small clearance between them and the axes is ordinarily to limit the deviations of the axes BB from their normal transverse position to very small amounts, for any tipping is almost instantaneously corrected and relatively large unbalanced loads may be applied suddenly without large disturbance of the gyroscopes. We shall return to this matter later.

The discussion thus far has considered what occurs while the car stands still or moves upon a straight track or cable. A single gyroscope would have been sufficient to produce all the results reached so far. The two have, however, been shown to act in unison so far, and the two become necessary only by reason of the forces brought into play in rounding a curve in the track.

So far as the centrifugal force which is developed in running the car around a curve is concerned, it acts precisely like an unbalanced load in applying an angular impulse about T_1T_2 to tip the car off the track. We have already explained in detail how the gyroscopes operate to balance the car on the rail in such circumstances. It should be remembered that in rounding a curve the car is in balance not when its centre of gravity is vertically over the rail, but instead, when it lies in the line of the resultant of the centrifugal force and gravity, just as it must also stand inclined in case of sidewise wind-pressure.

The one thing, however, which we have not yet considered is the torque developed in each gyroscope about the longitudinal axis T_1T_2 by reason of the common precession of both gyroscopes in the same sense with the car itself about a vertical axis in rounding a curve in the track. Were it not for the toothed sectors A_1A_2, the axes B_1B_2 would both maintain their original direction in space while the car turned the curve, but, unable to do this by reason of A_1A_2, they are both forced to precess with the car. Suppose the car moves in the direction T_1T_2 around a curve that turns to the right as A_1 does, then the precession is clockwise viewed from above, and the torque developed in the right gyroscope is formed by placing our cork model of TUV with V to the right, U vertical and T horizontal, so that

T acts about T_1T_2 and clockwise looking from T_1 to T_2, while the torque in the left gyroscope is about T_1T_2 but clockwise looking from T_2 to T_1, as will be readily perceived by comparing the cork model before mentioned with U upward in the two while V in one case is opposite to that in the other.

The two gyroscopes, therefore, develop equal and opposite torques about T_1T_2 which are transmitted to the rigid frame EF through the bearings DD and they hold each other in equilibrium by means of internal stresses induced in the frame. While running around a curve to the right a tension is caused in F_1F_2 and an equal compression in $F'_1F'_2$.

The gyroscopes are both needed in this case in order that each may equilibrate and neutralize the torque of the other, which would otherwise infallibly overturn the car on attempting to run it round a curve. Furthermore, it is evident that in order to secure the existence of this dynamic equilibrium it is necessary that the two axial velocities V be at all times equal and opposite.

It is not, however, necessary that V remain, at all times, constantly of the same value. The high speed of 3000 r.p.m. proposed by the inventor is for the purpose of ensuring that the product MV on which the stability of the car depends shall be large without making the size and weight of the gyroscopes large. He estimates that for ample stability their weight may then be only 4 per cent. of the weight of the car, or less.

Under those conditions the gyroscopes would store so large an amount of rotary energy (which is measured by $\frac{1}{2} MV^2$) that the fluctuations of velocity V, due to the expenditure by friction on G_1G_2 and otherwise, would be practically imperceptible in case the power applied by the synchronous motors to maintain V is sufficient in the long run to make good all losses by friction. In any case the power needed by the gyroscopes would be inconsiderable compared with that required for the propulsion of the car.

The foregoing discussion has all depended upon equation (4) and its applicability to the gyroscopic interactions actually occurring in the proposed arrangement. Equation (4) assumes that the axes BB are in their normal transverse positions at right angles to T_1T_2. But owing to the precessions about DD we are compelled to consider what modifications are necessary in order to take into account the effect of such deviations in the positions

of BB as may take place. Let d designate the amount of this angular deviation from the normal position at any instant. Then the angular velocity V may be regarded as made up of two components, viz., $V \sin d$ about an axis parallel to T_1T_2 and $V \cos d$ at right angles to T_1T_2, of which the latter component alone is effective in equation (4) which may be written:

$$T = MUV \cos d \qquad (4)$$

From this it is seen that with a given torque T the precession U increases with the deviation d, though the deviation is in fact usually confined to such small values that the precession is but slightly varied from this cause.

The practical effect so far as balancing is concerned is the same as if the gyroscopes were in normal position with axes at right angles to TT, and rotating with velocities $V \cos d$, and besides that there was an additional pair of gyroscopes exactly like these mounted on axes parallel to T_1T_2 and rotating with velocities $V \sin d$. The effect of these latter, were they in action, will be readily seen to be nil so far as unbalanced loads on the car are concerned, as well as their effect on the centrifugal action in rounding a curve; but not so in regard the precessional effect in rounding a curve, which precession, as previously remarked, consists in a turning of the whole car including the gyroscopes about a vertical axis.

In case the gyroscopes stand at a deviation d while rounding a curve the stresses before described as produced in FF are diminished in the ratio of V to $V \cos d$, the latter being the component of the angular velocity of the gyroscopes in the plane of the frame. Besides this stress, a twisting stress is induced in the frame by the angular component $V \sin d$, the component rotation parallel to $T_1\ T_2$, which exerts a torque about an axis perpendicular both to the axis of precession which is vertical and the axis of rotation TT, *i.e.*, about CC. This torque, therefore, consists of equal forces parallel to T_1T_2 applied to the frame at the four points D_1, D'_1, D_2, D'_2, such that those at D_1 and D'_2 act in one direction and those at D_2 and D'_1 in the opposite direction, thus causing a bending stress in the frame EF so that the torque exerted by one gyroscope is neutralized by the other, and the effect upon the car is nil.

It thus appears that no disturbance of the balance occurs by

reason of the deviation caused by the precession occurring during the righting of the car. The sole effects are some slight variations in the rate of the precession and in the stresses to which the frame is subjected, matters which have no influence upon the action of the gyroscopes in righting the car.

It is furthermore evident that the gradual or instantaneous elevation of one end of the car above the other, such as might occur in running on a slack cable would, since it is a precessional rotation about an axis parallel to *CC*, have no effect, at least while the axes *BB* are in their normal position perpendicular to *TT*. The almost impossible case of such precession taking place during the continuance of a deviation *d* of perceptible magnitude could also be readily discussed, but is practically negligible since the deviation *d* actually flutters back and forth each side of zero in almost infinitesimal instantaneous excursions that check every attempted lapse from an upright position at its very beginning, and simultaneously with the attempt, the only lag in action being the time required for the movement necessary to tip the car far enough to reduce the clearance between the axis at *B* and the plate *GH* to zero. That clearance may be made as small as desired.

The question that naturally arises respecting this car, in the mind both of the engineer and the layman, is as to the limits of its stability. How much of an upsetting torque is it able successfully to withstand? It is evident that the larger the moment of inertia and rotary velocity of the gyroscopes the greater the stability, as appears also from equation (5). Brennan has stated that the weight of the gyroscopes need not exceed some 4 or 5 per cent. of that of the car. In his experimental car their weight is nearly 7 per cent. of the unloaded car, but perhaps may not exceed 4 or 5 per cent. of its total weight when loaded.

The point of danger in the apparatus is reached when the precession *U* has been so long operating as to carry the deviating axle B_2 (Fig. 4) to the end of the friction plate G_2. The car must be righted before the deviation reaches this point or the car will upset. A deviation of more than 30 degrees would apparently be unpracticable, and in practice 10 degrees or 15 degrees is probably nearer the limit.

In order that the car be righted with such promptness as to avoid this danger, U' in equation (6) must be large, which in

turn requires T' to be large. Now T' is the torque about a vertical axis due to the friction of the axle B_2 as it rolls and slides upon G_2. This torque T' depends upon the product of the pressure of B_2 upon G_2 and the coefficient of friction between these. It has already been shown that the precession U is unaffected by T'. It is U' alone that is affected by T'. Now it would seem that the only thing necessary to make U' of any desired amount would be some means of increasing T' *ad libitum* before the deviation reaches its limit. To ensure ultimate safety either the coefficient of friction should in some manner be made to increase enormously before the limiting deviation is reached, or the pressure between B_2 and G_2 should be enormously increased in some automatic manner before reaching that limit. It would appear quite practicable to so arrange magnetic coils about B_2 as to have an electric current pass through more and more of them as B_2 approaches its limit of deviation and by that method automatically increase the magnetic pressure between B_2 and G_2 to any desired extent as the limit is approached, thus making T' and consequently U' both increase enormously at the limit. It would seem as if some such device must be adopted if occasional overturning from high winds and other accidental causes are to be avoided. The inertia of the gyroscopes in Brennan's experimental car is not known as yet, but computations based on assumed data make it probable that a very high wind causing a pressure of 30 pounds per square foot against the sides of a car of ordinary construction might cause a total precessional deviation of 30 degrees in a fraction of a second, from which the suddenness with which the car must be tilted to oppose the wind may be inferred and the necessity for some such automatic safety clutch is evident.

There is an action of the gyroscope still remaining which it is important to consider in connection with mono-rail car, which action is included under the head of 'nutation,' so called. The actions treated thus far in this paper have not taken into consideration the inertia effects which are brought into play about the vertical and longitudinal axes of the car by reason of the sudden or gradual application of unbalanced loads. Consider the effect of a weight W suddenly applied at B in Fig. 2. The discussion heretofore given treated the precessional motion as already established and its steady continuance was ensured by

the moment of W acting about C. In suddenly applying a weight W at B we have to consider the phenomena occurring during the establishment of the precession due to W. This precession, consisting in a constant, angular velocity about a vertical axis through C, must necessarily arise by the application of an angular acceleration (constant or variable) about the same axis which is resisted by a corresponding couple (constant or variable) due to the inertia of the gyroscope.

During the establishment of the precession due to W there is therefore a resisting couple about the vertical axis due to inertia, which acts in addition to everything previously taken into account. Such a couple produces precession about CE Fig. 2 in such a way as to allow W to begin to move downwards. This is clearly what should occur, since the precession does not become large enough to support W until the precession reaches the value required by equation (5).

The motion just described is the beginning of the nutation. The precession about the vertical will gradually increase until it is sufficient to support W were it at rest, but by that time W has acquired a velocity and momentum such as to carry it still further downward before it can be stopped. In thus being stopped in its course, W by its inertia exerts a couple which continues to increase the precession beyond the amount necessary to simply support W, so that by the time W has ceased to move downwards the precession is so large as to give W an upward velocity during the time necessary to reduce the precession. It may readily be shown that W will be carried upward to the level from which it started, while the precession will also be diminished to the value it had to begin with. This oscillation of W up and down in unison with the increase and decrease of precession occurs harmonically, and constitutes the nutation.

In case the weight W is applied uniformly and gradually during the nutation, so that the whole of it is applied in course of the downward motion, it is evident that it will have half as much effect in causing nutation as if applied suddenly.

The relations just stated would enable us to investigate the amplitude and period of the oscillation were it important to do this. But as will now be shown such oscillations should not arise in the mono-rail car and hence we omit the investigation.

In the mono-rail car the friction plates are designed for the

very purpose of producing a couple about the vertical axis opposed to the inertia couple which causes nutation. If properly designed the friction couple neutralizes and greatly exceeds the inertia couple due to any load likely to come upon the car. It will then happen that the car will not give way under an imposed load at all but will begin at once to bring the centre of gravity of load and car over the rail without any preliminary nutation, which would be a motion in the opposite direction. It might be possible, however, for a weight falling from a sufficient height to set up a small oscillation.

X-RAY AS DENTAL DETECTIVE. (*Popular Electricity*, ii, 12.)—A Cleveland oculist had a patient whose right eye was unaccountably inflamed, and the inflammation refused to yield to local treatment, which was evidence that the cause was not in the eye itself. The oculist sent the patient to a dentist, who, after close search, found a slight abscess at the root of the left eyetooth. On treating this abscess in the usual way the eye gradually improved. A year later the other eye was troubled in a similar manner, but no corresponding abscess was externally discoverable in the right eyetooth. However, the dentist drilled down to the root of the tooth and found a slight abscess. By curing this, the eye also was cured.

It occurred to the dentist that such cases might occur again, and that it would not always be desirable to bore into sound teeth on the chance of locating the trouble. So he tried if the X-rays would locate the seat of trouble and found them effective.

A NEW NITRIDE OF CARBON. (*Bull. Soc. d'Encour.*, 113, 3.)—Cyanogen, C_2N_2, discovered by Gay Lussac in 1815 is a nitride of carbon. MM. Ch. Moureu and J. Ch. Bongrand, at the meeting of the Academy of Sciences on Jan. 24, 1910, announced the isolation of a sub-nitride with the formula C_4N_2, by the separation of water from the butine-diamide, thus,—

$$\begin{matrix} CONH_2—C—C—CONH_2—2H_2O= \\ N—C—C—C—C—N \text{ or } C_4N_2. \end{matrix}$$

The product obtained, which is dicyanacetylene, can be recognized as a carbon cyanide $C_2(C_2N)$. The product appears as fine white needles, melting at 21° C. It boils at 76° C., its odor, its irritating properties and its vapor resemble those of cyanogen. It burns easily, its vapor ignites spontaneously in the air at about 130° C.; that of carbon disulphide ignites at about 150° C.

THE COLLOID NATURE OF THE COMPLEX INORGANIC ACIDS.

BY

EDGAR T. WHERRY, Ph.D.

(*Presented at a Stated Meeting of the Section of Physics and Chemistry, held Thursday, March 3, 1910.*)

[Substitution of one oxide by an equivalent quantity of a similar oxide, *e.g.* phosphorous pentoxide by arsenic pentoxide, changes the ratio of all the oxides to each other. Moreover, certain of the tungsten complexes crystallize in the isometric system, as is shown by measurement of the crystals, but have orthorhombic structure, as is shown by their behavior toward polarized light. Hence these compounds probably are adsorption colloids in which the physical molecule of tungsten trioxide is composed of its chemical molecules, arranged in the isometric system (octohedron truncated by a cube). The chemical molecules of the other oxides are arranged in the spaces between the chemical molecules of the tungsten trioxide, and thus produce a stress in the physical molecule of the latter, and cause the orthorhombic structure revealed by polarized light.]

THE term "complex inorganic acid" was proposed by the late Wolcott Gibbs in 1879[1] for "A class of compounds which may be considered as formed by the union of two or more acids with elimination of water in such a manner as to form a whole, which in its chemical relations behaves like an acid containing a single radical."

The most familiar example of this class of substances is, of course, phosphomolybdic acid, the insolubility of whose salts with ammonium and the alkaloids render it of great importance in analytical chemistry. To this body various formulas are assigned, from $18MoO_3.P_2O_5$ to $24MoO_3.P_2O_5$, and it is well known that the most careful attention must be paid to the conditions of its preparation in order to be certain of reproducing a desired composition. The "union" between the two acids is evidently different from anything ordinarily encountered in chemical science.

The labors of Gibbs during some fifteen years subsequent to

[1] Amer. Chem. Jour., i, 217.

his first publication upon the subject brought to light a vast number of analogous bodies, and many more have since been prepared by Professor Edgar F. Smith at the University of Pennsylvania, and by other investigators. From simple combinations of two acid oxides it has been found possible to pass to others with as many as five, for instance, phospho-arseno-venado-vanadico-tungstic acid, described as $14P_2O_5.2As_2O_5.34V_2O_5.41V_2O_3.194WO_3$; nearly all of the dioxides and sesquioxides, acid and basic, rare earth and heavy metal, have been introduced, and even the same element in different states of oxidation, as in the example cited. Most of these complexes are known as ammonium salts, yet various other salts, as well as the free acids, have been prepared by double decomposition; although consideration of the number of combinations possible shows that the field is by no means exhausted.

The mere preparation, analysis, and characterization of these bodies, laborious as it is, cannot be regarded as completing their study. We can only claim to know them, in a true scientific sense, when we have demonstrated the nature of the forces which hold the elements together, the reasons for the remarkable proportions observed to exist,—in short, when we have discovered and explained their constitution. It is the purpose of the present note to call attention to certain of their properties which seem to throw some little light on this matter, although complete understanding of their nature is of course still as far distant as of that of the majority of inorganic compounds.

The question as to whether these complexes are really chemical compounds may well claim our attention first. Gibbs, who did so much pioneer work in their preparation and analysis, evidently regarded them as such, and he even attempted to derive structural formulas for a few of them. But such formulas occupy much space—one all but two lines of a page in the *American Chemical Journal*,[2]—and really add nothing to our knowledge of them. And later writers have wisely refrained from further speculation of this sort.

The evidence as to their true nature may be summed up in a few words as follows:

They appear to be compounds because of, (1) Their reproducibility, with remarkably constant compositions, under widely

[2] Amer. Chem. Jour., 1881, iii, 414.

different conditions. (2) The tenacity with which the oxides stick together, through a variety of reactions, a property emphasized most strongly by the difficulties attendant upon their analysis. (3) The fact that the majority are well crystallized.

Against this interpretation we have apparently only the difficulty of explaining their constitution.

Yet the case is by no means as one sided as might appear at first sight. It must be granted that, as far as (1) is concerned, they have not been sufficiently studied from a physicochemical point of view for us to assert that their compositions are actually definite. In little of the work carried out upon them so far has there been any systematic variation in the conditions, and indeed the variability of some of them is only too well known (witness the notorious difficulties in the determination of phosphorus in pig-iron and steel). In fact Gibbs was able to prepare phospho-molybdic acids in which the $MoO_3:P_2O_5$ ratio was successively 5, 16, 18, 20, 22, and 24, while the corresponding arsenic complexes gave 6, 7, 16, and 20.

The strong attachment of certain of their constituents, introducing so many unexpected difficulties into their analysis, can also hardly be regarded as a definite proof of their compound character, however interesting it may be. It will fall in with any explanation of their nature that at present suggests itself.

Their crystallizability merits, however, more consideration. According to the usual views, based upon sound observation and experience, this property is to be regarded as a safe criterion of the definiteness of a chemical compound. Yet in these bodies we have two rather strikingly contradictory features: (1) The more complicated their makeup, the better they crystallize; and (2) they appear to be for the most part isomorphous. While to be sure the simpler ones are often amorphous, or show various types of crystallization, practically all of the 3, 4, and 5 oxide preparations, both of molybdenum and tungsten, present a form suggesting that of common alum, the octahedron truncated by the cube. Most of the crystals are opaque and dull on the surface, so as to be unsuitable for examination by ordinary methods of physical mineralogy. The series of phospho-vanado-molybdates recently prepared by Dr. William Blum, under the direction of Professor Smith, at the University of Pennsylvania, were however brilliant and transparent enough for such study, and the

results obtained upon them suggested the presentation of the present note.

The habit of these crystals is, in a general way, that mentioned above—the octahedron with vertices truncated by cube faces. One peculiarity is, however, very noticeable: the apparent cube faces are not all alike, but appear to be of at least two kinds, two opposite faces being almost invariably large, while the remaining four are inclined to be smaller, or in some cases absent altogether, immediately suggesting the possibility that some other crystal system than isometric is represented. When the angles between the faces were measured, however, they proved to agree sensibly with those of the cube and octahedron; the reflections were not sufficiently good to yield measurements of extreme accuracy, yet the variations from the theory between octahedral faces, for instance, rarely exceeded 5 minutes, and no systematic relation could be traced between them and the position of the different "cube" faces. Study of a more extensive series of crystals would be highly desirable in this connection, and it is hoped that opportunity will be found for it before long.

When cross sections of the most transparent crystals were examined in convergent polarized light, more definite results were obtained. The direction perpendicular to the two "cube" faces showing the larger development actually proved to be a peculiar one. Sections cut parallel to these planes gave a fine interference figure, which at first sight looked uniaxial, corresponding to the suspected tetragonal habit, but careful observation showed that the figure was really biaxial, with an optical axial angle of about 5 degrees, so that the system may well be orthorhombic. Five different preparations examined showed identically the same phenomena; but it has unfortunately not yet been possible to extend similar studies to other series of isomorphous or pseudo-isomorphous complexes.

The ordinary conception of isomorphism implies a correspondence in chemical as well as crystallographic character. These complexes, as usually formulated, certainly show no particular resemblance in the former respect. But it is quite possible to bring them into a more directly comparable form, a problem which may well occupy our attention at this point. The necessity for retaining the old dualistic or separate oxide formulation is of course evident. It will surely be easier to find an explana-

tion of the nature of the substance if we have it before us as $20MoO_3.P_2O_5$, than if it is stated as $Mo_{20}P_2O_{65}$; and with increasing complexity the need for such separation becomes still more imperative, as has been recognized by all the workers in the field.

But the derivation of the formulas from the analyses is another matter. The method universally adopted has been the one customarily employed in analytical work: to calculate the results so as to give a unit quantity of the oxide present in smallest amount, and then express the others in terms of this. For the simpler complexes this may be satisfactory enough, as it really represents our total knowledge concerning them. Thus, we write $20MoO_3.P_2O_5$ rather than $40MoO_3.2P_2O_5$, because it is the simplest possible expression; and the use of the same method throughout inorganic practice (is not $KMnO_4$ preferable to $K_2Mn_2O_8$?) justifies its retention here.

On the other hand, as soon as we pass to the more complicated bodies,—those in which three or more oxides are concerned,—difficulties begin to appear. The most serious of these is the frequent necessity for using half molecules; thus, in the work of Dr. Blum one ammonium salt called for the formula $7(NH_4)_2O.5\frac{1}{2}V_2O_5.16\frac{1}{2}MoO_3.50H_2O$, and another 8, 10½, 11½, and 50 of these oxides respectively.[3] And while the difficulty could here be removed by doubling the formula, necessity is sure to arise for trebling it in other cases, or indeed multiplying it indefinitely if the analytical work is sufficiently accurate. Furthermore, a slight error in the determination of the oxide present in smallest amount—and these are the very ones whose estimation presents the greatest uncertainty—becomes considerably magnified in its application to the others.

There is, however, a simple way to overcome these difficulties, consisting merely in the referring of the various constituents to a unit amount of the oxide present in largest amount, to that of molybdenum or tungsten. It would appear most practicable to make this oxide have a value of 100, although in special cases other values might be used. The formulas will then not only be much closer to the analytical results, but, above all, the different complexes will become directly comparable.

[3] Jour. Amer. Chem. Soc., xxx, 1908, 1860.

Thus instead of the unsatisfactory

$$106H_2O.15(NH_4)_2O.2P_2O_5.6V_2O_3.44WO_3$$

and

$$98H_2O.17(NH_4)_2O.2As_2O_5.14\tfrac{1}{2}V_2O_3.29WO_3,$$

we get

$$240H_2O.34(NH_4)_2O.4P_2O_5.13V_2O_3.100WO_3$$

and

$$335H_2O.58(NH_4)_2O.7As_2O_5.50V_2O_3.100WO_3.$$

In the majority of cases of isomorphous relations between two elements we find them entering compounds with like valence and in equal amount,—for example, $CaCO_3$, $MgCO_3$, $FeCO_3$, $MnCO_3$, etc., all contain one atom of the base. But extensions of the conception of isomorphism are required in other cases. PbS may well be regarded as isomorphous with Ag_2S, the metals here presenting the same total valence. Even this requirement is not essential, for in FeS_2, FeAsS, and $FeAs_2$, a strictly isomorphous series, the valences seem to vary. And finally only the general grouping of the atoms may be alike, as in the well known case of $CaCO_3$ and $NaNO_3$. In the complexes we find a still further divergence, the general rule appearing to be that replacing one element by another of greater atomic weight may cause increase in the relative number of atoms, not only of the latter, but also of all of the other constituents.

The tendency of chemical crystallography during late years has been largely toward the geometrical explanation of crystal forms. We have now the strongest reason to believe that the heat energy of bodies resides not in rapid motion of the atoms in the molecules, but instead in the motion of the corpuscles within the atoms themselves. Accordingly, it is permissible to represent every crystallized substance by a "point-system," or arrangement of points in space, possessing the proper elements of symmetry.[4] Three of these may be constructed for the isometric holohedral group, to which our crystals appear to belong; and of them, the one having the points most closely packed in the direction of the dodecahedron plane corresponds exactly to the apparent structure exhibited, that of the cubo-octahedron.

That it is the tungsten (or molybdenum)which determines the crystal form here is self evident; because of the relatively

[4] Compare Tutton, Crystalline Structure and Chemical Constitution, London, 1910, Chapter 16.

large size of these atoms it is equally clear that the closest possible manner of packing them will leave relatively large spaces for the interpenetration of other point systems; and by regarding the other oxides as entering in this manner, we have a comparatively simple explanation of the relations shown in these complexes. Suppose into a point system of tungsten atoms we introduce phosphorus pentoxide; this will distribute itself through the interspaces, and cause a slight distortion of the original structure. As pointed out by Groth,[5] the cubo-octahedral structure in question requires a comparatively slight deformation to cause it to pass into the orthorhombic system; which is the very condition indicated by the behavior of the specimens described.

When arsenic is introduced instead of phosphorus, a similar distortion might be expected, although the larger size of the arsenic atom would naturally cause it to be greater in amount. But it is evident that the greater the distortion of the original structure, the larger will be the interspaces formed, and the more atoms of the various elements concerned will be able to enter. In this conception we therefore have a simple explanation of the relations shown by the various complexes. Had we at our command numerical data concerning the relative spaces occupied by homologous atoms, it would appear to be quite possible to predict in advance the composition of any desired combination; and the study of a sufficient number of these bodies may ultimately lead to this result.

Viewing these complexes, then, as governed by geometrical rather than by chemical laws, it is surely not permissible to call them chemical compounds. It would seem, however, that they are but a step removed from the so-called "adsorption compounds" of colloid-chemistry, although to be sure the difference, that of crystallizability, is usually regarded as a fundamental one. But it is now recognized that many adsorption compounds, especially among natural minerals, are able to pass, by insensible gradations, from their usual amorphous condition to a crystalloid state. Now in the comparatively large nuclear atoms molybdenum and tungsten, the crystallization force might be expected to be unusually strong; so that these complexes may well be regarded as to a certain extent bridging the gap between the colloid and crystalloid conditions of matter.

[5] Introduction to Chemical Crystallography (English Ed.), p. 42.

LUMIÈRE PROCESS OF COLOR PHOTOGRAPHY.

[The Report of the Franklin Institute, through its Committee on Science and the Arts on the Screen-Plate Process of Color Photography invented by Messrs. Auguste and Louis Lumière of Lyons, France. Sub-committee: Lucien E. Picolet, Chairman; Henry Leffmann, Urbane C. Wanner, William H. Rau, W. N. Jennings. No. 2432.]

So well has the photographic technologist been kept informed by the many contemporary periodicals relating to the subject, particularly in its more recent development and practice, that the state of the prior art may be sufficiently disclosed by but a passing mention of the results of other workers in the same field.

Processes of color photography may be classified under two distinct divisions: the one depending upon a purely physiological action of color sensation, the other upon its dispersion of well defined physical laws regardless of its physiological effect. Screen-plate processes depend upon the former action based upon the Young-Helmholtz hypothesis of three-color sensation, which states that the effect upon the human eye of any color whatsoever may be produced by the simultaneous action of suitable portions of three colors in much the same manner as varying hues are produced by the proper mixture of the three primary pigment colors. Prior to the acceptance of this theory, it was generally supposed that white light (transmitted) could be produced only by the re-composition of the spectrum.

The first successful application of the three-sensation theory to the production of pictures in the colors of nature was made in 1868 by Louis Ducos du Hauron, later perfected by F. E. Ives and others. This process consisted in making three negatives of the subject taken through screens uniformly colored red, green and violet, using orthochromatic plates. Only the red rays effect the first, the image formed consisting of a deposit of silver of a density dependent upon their intensity. The plates behind the green and violet screens were likewise effected by light of their respective colors. Positives from these three negatives viewed simultaneously through screens of the colors used in making the original exposure appear in the colors of the original object, the distribution of the silver deposit permitting the trans-

mission of the requisite amount of each quality of light to produce the color of the original. Screen processes are based on this principle but operate in a slightly modified form.

The exposure is made upon one plate instead of three, behind a screen whose surface is covered with an equally divided distribution of minute spots of the three primary colors or ruled with narrow parallel bands of the same colors arranged in cyclic order.

The photographic effect upon a plate taken behind such a screen is similar to that obtained in taking the three separate impressions, except that there is available for producing the tint required upon a given surface only about one-third of the total light illuminating the screen. This necessarily follows from producing the synthesis not by the superposition of the requisite proportion of each primary color allowed to pass, but by the adjacent arrangement of the primary colors, each one of which utilizes one-third the area of the surface covered by the three. The interval between these colors is exceedingly minute and the combined effect upon the eye is similar to a simultaneous view of each separate color.

The many attempts to commercially manufacture screen plates have been duly chronicled in the literature of photography and need not be further mentioned than to point out that until the advent of the Lumière "Autochrome" plate none proved commercially feasible.

The culmination of many years' experimenting towards this end is embodied in French patent No. 339223, granted to A. Lumière and Sons, of France, dated December 17, 1904, and three supplements, numbered, respectively: 3891, 4290 and 7230. As there described, the plates are prepared by first applying to the glass support a layer of transparent adhesive material upon which is dusted suitably stained transparent granules, preferably of potato starch in the form of a fine powder. These granules adhere to the plate in a single layer, forming interstitial spaces which are covered by a subsequent dusting over with some minutely divided opaque powder.

The screen is varnished and is then ready to receive an orthochromatic emulsion, forming a plate which may be treated in somewhat the same manner as the common photographic dryplate. Such a plate possesses the same optical peculiarities found

in the three-plate screen process necessitating the use of a color screen to equalize the exposure. As now manufactured, the necessity for covering the open spaces between the colored particles is overcome. This is done by flattening out the particles in a roller press, which, expanding laterally, cover the unoccupied spaces, forming a mosaic composed only of the colors required in the screen.

The manipulations required and the precautions to be observed in producing a negative are described at length in a pamphlet supplied by the manufacturers and in current photographic periodicals.

Briefly, the dark-room process consists of a time development in a covered tray, a treatment with potassium permanganate to eliminate the reduced silver, and a subsequent development in the light to produce a positive image. Intensification and final varnishing complete the process.

It might be expected that positives could be obtained by contact printing from the negative resulting from its first development, as in the common monochrome processes, but it can be easily demonstrated that unless the like color elements of the negative and plate screens exactly coincide, positives cannot be produced in this way and the process is, consequently, restricted to the production of a single transparency for each exposure. The ease with which the operations required can be performed was amply demonstrated to the sub-committee. Transparencies were made at the Institute and every operation in their production witnessed by the sub-committee. A comparison with the originals proved that the various tints were reproduced with great fidelity.

The exact nature of the sensitive film has not been furnished by the manufacturers; they state, merely, that collodion enters into its composition. Though an important feature, it does not appear to your sub-committee to have other than secondary importance in comparison with the production of the color screen, which, hitherto, has not been successfully accomplished upon a commercial basis.

The keeping quality of the plates is somewhat inferior to common dry-plates, being more susceptible, according to report, to climatic influence than the latter. It is commonly understood that orthochromatic plates keep less well than others and it is to

be expected that the autochrome plates, subjected as they necessarily are to a particularly thorough treatment of orthochromatizing dyes, should suffer somewhat in keeping quality. The makers, however, furnish these plates under a time limit guarantee as is now frequently done with many perishable photographic materials.

There are undoubtedly some drawbacks to the process. The plate must be viewed by transmitted light, the illumination is subdued by the relatively large surface covered by the silver deposit required to screen extraneous color; replicas cannot be made, the time of exposure is greater, and, finally, the manipulations are more numerous than is usual in photographic processes. These objections are of relatively minor character when the state of the art is considered. The Messrs. Lumière have succeeded in devising a process of producing transparency photographs faithful to the colors of nature and readily available to all who are conversant with current photographic methods.

The Institute considers this achievement in the art one of the most important advances of the day and entitled to the highest commendation and accordingly awards to Auguste and Louis Lumière of Lyons, Monplaisir, France, the ELLIOTT CRESSON MEDAL for their Screen-Plate Process of Color Photography. Attest:

JAMES CHRISTIE,
Secretary.

PHILADELPHIA, November 3, 1909.

INTERNATIONAL PHOTOGRAPHIC EXPOSITION. The "Photographische Gesellschaft zu Riga" will hold such an exposition in Riga from July 28 to September 28, 1910. The exhibits will be divided into nine groups: (1) Scientific photography; (2) photography in colors; (3) artistic photography; (4) snapshots, travel, scenery, etc.; (5) technical and architectural photography; (6) photography for reproduction (press and printing methods); (7) photography for moving pictures; (8) photographic apparatus, supplies and chemicals; (9) literature pertaining to photography.

Exhibits should be plainly marked "Internat. Photogr. Ausstellung, Riga, 1910" and forwarded to Mr. Leopold Ewald, Spedi-tur, in Stettin, Germany, where they must arrive not later than June 14, 1910.

MODERN METHODS OF LIGHTING.

BY

ROBERT H. BRADBURY, Ph.D.,

Head of the Department of Science at the Southern High School.

RESUMÉ OF A POPULAR LECTURE DELIVERED AT WITHERSPOON HALL, FRIDAY EVENING, FEBRUARY 11, 1910.

THE possibility of producing light without the aid of very high temperatures was shown by mixing a solution containing pyrogallol and formaldehyde with 30 per cent. hydrogen peroxide. The vessel glowed with a strong red light, but remained cool enough to handle.

However, practical lighting is based upon heat. Some substance, usually a solid, is heated until it shines, *e.g.*, arc and incandescent lamps, calcium light. In candle and gas flames the shining solid is carbon. The mercury arc, and the flaming arc are exceptions, for in them the luminous source is a vapor.

When a solid is heated, the radiation consists entirely of heat-rays, up to about 700° F., when an unsteady gray light appears. This passes into dull red, yellow and white, as the temperature is raised. A jumble of vibrations is produced in which the heat-rays greatly predominate, but the higher the temperature, the greater the fraction of the energy given off as light. The theory of radiation has been worked out in detail for the "black body," *i.e.*, a body which absorbs all the radiation which falls upon it, reflecting none. However, actual substances are not black bodies. Their behavior when heated can only be determined by experiment. The effort of the illuminating engineer is to find solids which are sufficiently refractory, and which when heated, radiate a large fraction of the total energy in the luminous form. In the search for such substances the periodic law has given assistance since they always occupy the neighborhood of minima on Lothar Meyer's curve of utmost volumes. At the enormous temperature of 12000° F. a black body would radiate 50 per cent. of its energy in the visible form. If all energy could be radiated as light it would be possible to maintain a white source with an expenditure of only .08 watt per c.p.

The history of the gas industry was briefly sketched. With the aid of slides and specimens, the manufacture of Welsbach mantles was taken up in detail. A bar on which burned ten mantles, varying in composition from pure thoria to 10 per cent. ceria illustrated the striking variation in c.p. with composition. These illustrations were made possible by the cordial co-operation of Mr. H. S. Miner of the Welsbach Light Company.

Turning to the electric field, the wire (metal filament) lamps formed the next subject. Sample lamps from 16 c.p. to 100 c.p. with tantalum and tungsten filaments were shown in operation. These were furnished by the Philadelphia Electric Company.

The most striking advance in arc lamps is the flaming arc, which reaches the extraordinary efficiency of 0.2 watt per c.p. The flaming arc was made in a simple manner by sprinkling some fluorspar into a hollow, made in the lower of a pair of ordinary carbons. The light became yellowish and a great increase in intensity occurred. The "Aurola" Flaming Arc (3000 c.p.) was shown in operation.

The interesting increase in efficiency and steadiness which is achieved

by the use of slender carbons was referred to and illustrated by the "Economy," a recent Siemens lamp of this type.

The Moore Vacuum Tube was briefly described and illustrated by Geissler tubes containing hydrogen, nitrogen, helium, neon, argon, krypton and xenon, which phosphoresced, each with its own color, under the discharges of a powerful induction coil.

The success of the electrical experiments was due, chiefly, to the co-operation of Mr. Werner Kaufmann.

Mr. Reuben T. Shaw assisted with the experimental portion.

ELECTRIC-STEEL REFINING. (*Journ. Soc. Chem. Ind.*, xxix, No. 6.)—Three Héroult electric-steel furnaces are being erected in Sheffield for the manufacture of tool steel, of a quality equal to crucible steel. By the adoption of the Héroult method, the value of ores low in sulphur and phosphorus will diminish and vast deposits of a cheaper ore will become available for the production of the highest class of steel, while the capacity of existing open-hearth and Bessemer plants will be largely increased. By the use of cheaper raw material and the increased output of existing oxidizing furnaces, the cost of electric refining may be counter-balanced. The Bessemer process will probably receive a new lease of life working conjointly with the electric furnace. Many specifications now demand open-hearth rails, and even if the Bessemer process be used, the reserves of suitable ore are decreasing and the price is rising. There are two alternatives—to abandon the Bessemer plant and replace it by open-hearth furnaces or to retain the Bessemer plant in conjunction with the Héroult furnace. The U S. Steel Corporation has adopted the latter course. It is probable the same procedure will be followed in England on the West Coast; and on the Northeast Coast a furnace is now being constructed to refine 200 to 250 tons of steel per day from a Talbot furnace.

SMOKE NUISANCE.—The abatement of the smoke nuisance in Glasgow, Scotland, has been under discussion by the local press, the municipal authorities, the business men, educationalists and the citizens generally. The result is that the initial steps have been taken by the corporation to arrange for the holding of an exhibition of the most up-to-date appliances for the utilization of gas for lighting, heating and cooking, and for a display of all kinds of exhibits and appliances for smokeless fuel This exhibition should afford American manufacturers of gas and electrical appliances for cooking and heating purposes an excellent opportunity to display their numerous economical and labor-saving devices in this market.

FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting, held Wednesday, May 18, 1910.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 18, 1910.

President WALTON CLARK *in the Chair.*

Additions to membership since last report, 11.

The paper of the evening on "Some Facts about Electrical Insulation" was read by Prof. Arthur J. Rowland of the Drexel Institute, Philadelphia. The speaker discussed the question of insulation resistance of electrical apparatus and circuits. He exhibited and described a direct reading megohmmeter, the invention of Mr. Sidney Evershed, and illustrated, by means of a projection lantern, the effects of moisture and temperature on insulation. After a brief discussion the paper was referred to the Committee on Publications and a vote of thanks was tendered to the speaker. Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Proceedings of the Stated Meeting, held Wednesday, May 4, 1910.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 4, 1910.

MR. THOMAS SPENCER *in the Chair.*

The following reports were presented for final action:

(No. 2462.) Blanton's Shaft Couplings, Shaft and Hub Connections. (Adopted, Certificate of Merit.)

(No. 2487.) Baekeland's Bakelite. (Adopted, John Scott Award.)

The following report was presented for first reading:

(No. 2463.) Murray's Safety Devices for Electric Wiring.

The following gentlemen were elected to fill vacancies on the committee:

To serve nineteen months, Dr. F. A. Genth; to serve two years and seventh months, Mr. Harold Calvert.

R. B. OWENS,
Secretary.

FRANKLIN INSTITUTE

MEMBERSHIP NOTES.

At the Stated Meeting of the Board of Managers, held Wednesday, May 11, the following gentlemen were elected to membership:

Resident.

WALTER TIBBITTS, 5712 American St., Olney, Philadelphia, Pa.
WILMER ROBERTS, Palmyra, N. J.
JOHN P. EATON, 5702 Spruce St., Philadelphia, Pa.
CHARLES BLIZARD, Electrical Engineer, Vice-president the Electric Storage Battery Company, Philadelphia, Pa.
WILLIAM C. RUMFORD, 3144 North Twelfth St., Philadelphia, Pa.

Non-Resident.

WILLIAM J. ROBINSON, President, United States Linen Flax Corporation, 10 West Thirty-third St., New York City.
ANDREW ALLAN, JR., Manufacturer of Bearing Metals, 486 Greenwich St., New York City.
EDWARD WESTON, D.Sc., LL.D., President Weston Electrical Instrument Company, Newark, N. J.
MORTON G. LLOYD, Ph.D., Technical Editor, *Electrical Review and Western Electrician*, Marquette Building, Chicago, Ill.

Associate.

HERBERT MILLS, 721 Butler Street, Philadelphia, Pa.
FRANK BYRNES, 535 West Montgomery Avenue, Philadelphia, Pa.

Change of Address.

JOHN K. CLASS, Camden Y. M. C. A., Camden, N. J.
MARY C. DUBOIS, 1733 Pine St., Philadelphia, Pa.
WILLIAM J. HAINES, 1011 Chestnut St., Philadelphia, Pa.
GEORGE R. HALL, Chappaqua, Westchester County, N. Y.
ALFRED J. MAJOR, Buckhill Falls, Pa.
J. WALDO SMITH, 165 Broadway, New York City.
WILLIS C. SQUIRE, R. 315 Jackson Boulevard, Chicago, Ill.
CHARLES H. WERNER, 37 Wall St., New York City.

OBITUARY.

WALTER CRAIG KERR, President of Westinghouse, Church, Kerr & Company, died on May 8th at Rochester, Minn. Mr. Kerr was born in 1853; he studied mechanical engineering, and after graduation from Cornell University became an assistant professor there. In 1883 Mr. Kerr connected himself with the Westinghouse interests, and later was elected president of Westinghouse, Church, Kerr & Company. He was a Trustee of Cornell University since 1890, also a director in the Westinghouse Machine Company and the Security Investment Company. With offices at No. 10 Bridge St., New York, Mr. Kerr spent the greater part of the last twenty years on Staten Island; he was a member of many scientific and social organizations.

LIBRARY NOTES.

Purchases.

BOHM, DR. C. RICHARD.—"Die Fabrikation der glühkörper für Gasglühlicht."
BOTHAS, LUDWIG.—"Massen-Destillation von Wasser."
CODDINGTON, HENRY.—"Treatise on the Reflection and Refraction of Light."
DUNBAR, DR. H. T. C.—"Principles of Sewage Treatment."
HEATH, R. S.—"Treatise on Geometrical Optics," Ed. 2.
NAGEL, OSKAR.—"Producer Gas Fired Furnaces."
NAGEL, OSKAR.—"Transportation of Gases, Liquids, and Solids by Steam, etc."
PEABODY, C. H.—"Naval Architecture."
PERRY, JOHN.—"Spinning Tops."
PHILIP, JAMES C.—"The Romance of Modern Chemistry."
RIEMER, T.—"Shaft Sinking in Difficult Cases."
ROSENTHAL, L. W.—"Practical Calculations of Transmission Lines."
RUER, DR. RUDOLF.—"The Elements of Metallography."
SCOTT, R.—"Automatic Block Signals and Signal Circuits."
SLOANE, T. O.—"Elementary Electrical Calculations."
SMITH, A. C.—"Suction Gas Plants."
SOPER, G. A.—"Modern Methods of Street Cleaning."
SPANGLER, GREEN and MARSHALL.—"Elements of Steam Engineering."
SPONS' "Workshop Receipts for Manufacturers and Scientific Amateurs." Two volumes.
STEWART, B.—"Handbook on Railway Surveying."
STEWART, A. W.—"Recent Advances in Organic Chemistry."
STRICKLAND, F.—"Manual of Petrol Motors and Motor Cars."
SVEDBERG, DR. THE.—"Methoden zur Herstellung Kolloider Lösungen anorganischer Stoffe."
SYKES, W. J.—"Principles and Practice of Brewing."
TAYLOR, H. DENNIS.—"A System of Applied Optics."
VAN DEVENTER, H. R.—"Telephonology Description of Modern Telephone Appliances."
VON SCHON, H. A. E. C.—"Hydro-Electric Practice."
WADSWORTH, M. EDWARD.—"Crystallography: An Elementary Manual for the Laboratory."
WEBB, W. L.—"Railroad Construction Theory and Practice."
ZERR and RUBENCAMP.—"Treatise on Colour Manufacture."

Gifts.

Bureau for the Safe Transportation of Explosives and Other Dangerous Articles, Report of the Chief Inspector, New York, 1910.
"Alcohol," by Dr. J. Starke, New York, 1907.
United States Coast and Geodetic Survey, Results of Observations, Magnetic Observatory at Sitka, Ala., 1905–06, Washington, 1910.
"Museo de La Plata Revista," vol. 16, Buenos Aires, 1909.
Sydney University Engineering Society, Proceedings, vol. 13, Sydney, 1908.
"Copper Handbook," by Horace J. Stevens, vol. 9, Houghton, Mich., 1909.
"Electric Power Plants," by Thomas E. Murray, New York, 1910.
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CURRENT TOPICS.

THE ACTION OF WATER ON LEAD PIPES. (*Bull. Soc. d'Encour.*, 113, 3.)—M. Olivier Ferrier has received the award of merit of the Société de Pharmacie of Paris for his treatise upon the action of water on lead and iron pipes. Water such as that of Vitre, which contains less than 3 milligrammes of calcium carbonate per litre, does not deposit a protective layer on the interior of lead pipes, especially if there be free carbon dioxide gas present; the nitrates and chlorides present tend to form small quantities of lead chloride, which dissolves, and larger quantities of hydrocarbonate. The author examines the behavior of different metallic pipes with waters containing but little lime. He concludes that lead pipes should be rejected, even when tinned; also iron pipes even when enamelled. His conclusion is that it is desirable to change the composition of the water, as is done at Sheffield and at Dessau, where its action on pipes is attributed to its too great purity, by adding a fixed quantity of lime, which has the further advantage of sterilizing the water, and of furnishing a mineralizing element to the human body.

THE MAGNESITE INDUSTRY IN INDIA. (*La Nature*, No. 1922.)—Considerable deposits of magnesite covering an area of more than 800 hectares (1976 acres) are found at Salem in the Madras Presidency. It exists in numerous irregular veins. The mineral is almost perfectly white, its density is about 3, and its hardness about 5. It contains 96 to 97 per cent. of magnesium carbonate, and a very little silica, chalk, and iron and aluminum oxides. By

calcining the magnesite in gas ovens at 800° C. magnesium oxide is obtained, which mixed with a solution of magnesium chloride, makes a very good cement. By heating to 1700° C. calcined magnesia is obtained from which refractory bricks can be made.

A WHITE BRAZING SOLDER (*Brass World*) good for use on iron and steel consists of copper 45 per cent., zinc 45 per cent., and nickel 10 per cent. The nickel gives the necessary whiteness and only raises the melting point very slightly. For brazing steel or iron, silver solder, which flows readily without oxidation and at a low temperature, is preferable, but on account of its cost a suitable substitute is sometimes desirable.

THE INJURIOUSNESS OF THE SMOKE FROM STEAM BOILER FURNACES. (*La Nature*, No. 1922.)—Attention has frequently been called to the damage done to the neighborhood by the production of smoke which contains corrosive or noxious gases, such as sulphuric or sulphurous acid or ammonia. To give an exact idea of the damage which such smoke can cause, samples should be taken at the base of the chimney to determine their composition. Sulphuric acid gas is retained in a suitable absorption apparatus, and determined as insoluble barium sulphate; sulphurous acid is determined in the same way after absorption and oxidation to sulphuric acid by iodine or bromine. The proportion, by volume, of sulphurous acid gas in the smoke varies 0.0001 to 0.0003 per cent.; it rarely reaches 0.001 per cent. The content of ammonia, ammoniacal salts and volatile products in the smoke has little or no relation to the injury they do. Recently attention has been directed to the smoke of locomotives, which diffuses quantities of sulphuric and sulphurous acid gases into the atmosphere which are far from negligible.

ON THE DECOMPOSITION OF CELLULOID WITHOUT IGNITION. (*La Nature*, No. 1922.)—According to Panzer the decomposition of celluloid without ignition gives, for 100 Gm.:

Nitrogen dioxide	12.4 Gm.
Nitrogen oxide	1.9 Gm.
Carbon dioxide	2.4 Gm.
Carbon monoxide	7.0 Gm.
Nitrogen	1.1 Gm.
Camphor	24.4 Gm.
Nitric acid	13.1 Gm.
Volatile organic matter	20.9 Gm.
Carbonaceous residue	16.8 Gm.

The greater part of the camphor is found unchanged. From the investigations of the author it appears that under these conditions the camphor acts as a denitrifier on the nitro-cellulose, form-

ing a nitrate 2 $C_{10}H_{16}O\ N_2O_5$, a colorless oil which is immediately decomposed by water. The explosions of the gases which celluloid evolves under the influence of heat, are probably due to the presence of this nitrate.

POLONIUM. (*Comptes Rendus*, 1910, 150.)—Several tons of uranium residues yielded 2 milligrammes of substance containing 0.1 milligramme of polonium. Fairly pure helium was isolated from the gases given off by a solution of polonium under a high vacuum in a quartz tube, due to the action of the X-rays emitted by this element. The life of radium is about 5300 times that of polonium (which is reduced to one-half in 140 days). The spectrum is being studied to ascertain if an inactive element is derived from it. Polonium, according to theory, is the last radio-active term in the series.

ON DISINFECTANTS AND THEIR USE. (*La Nature*, No. 1922.)—Most of the disinfectants, according to the bacteriologists, show a variable activity, in such a way that the test of a disinfectant upon a given species of bacteria, such as is generally made, does not usually agree with the ordinary disinfectant effect of the substance under examination. An ideal disinfectant would be a substance sufficiently active upon all the micro-organisms, yet not poisonous, inodorous, and sufficiently soluble. These conditions are partially attained by the halogen derivatives, the chlorides or bromides of naphtol, which are more active than most of the known disinfectants, with the exception of corrosive sublimate, and which are practically inodorous and not poisonous. Thus an alkaline solution of tri-bromo-naphtol, of 1 part in 250,000, kills staphylococci in two or three minutes, whilst a solution of lysol, of 1 part in 1000, does not kill them in less than 40 minutes. This substance is also very active against streptococci, the bacilli of diphtheria and typhus fever. It gives excellent results for disinfecting the hands.

ELECTRICITY FROM THE WIND. (*Popular Mechanics*, April, 1910.)—When the steam engine reached its development practically the only place where the windmill was retained in service was Holland. But a new use has sprung up for the windmill as a developer of electricity, and it has been re-christened a "wind-turbine."

In one type of wind-turbine, the wheel of galvanized steel is 16 ft. in diameter mounted upon a steel tower 50 ft. high, and all moving parts run on ball-bearings, and the transmission gear works in an oil bath. The generator used is of about 2 k.w. capacity and of 130 volts. Such a plant costs from $1000 to $1200, according to the size of the storage batteries.

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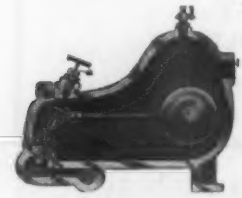

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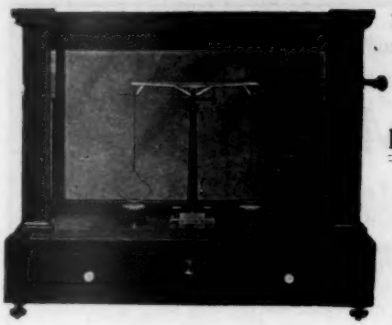

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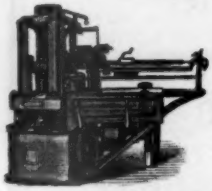

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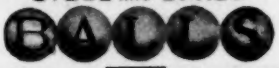

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3. The Board of Managers of the FRANKLIN INSTITUTE shall, before the first day of January, one thousand nine hundred and eleven, select three citizens of the United States of competent scientific ability, to whom the memoir shall be referred; and the said Judges shall examine the memoirs and report to the FRANKLIN INSTITUTE whether, in their opinion, any, and, if so, which of the memoirs is worthy of the Premium. And, on their report, the FRANKLIN INSTITUTE shall decide whether the Premium shall be awarded as recommended by the Judges.

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5. Should the Judges think proper, they may require the experiments described in any of the memoirs to be repeated in their presence.

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